AIR QUALITY IN THE NATIONAL PARKS

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NATIONAL PARK SERVICE

CLEARING THE AIR

SPECIAL REPORT

1988

Air pollution is clearly one of the most important environmental issues facing the National Park Service, the nation, and the world. Air pollution is affecting natural resources throughout much of the National Park System. Visibility reduction and biological effects, such as foliar injury to plants and trees, are some of the known effects of air pollution. Several park units are serving as key areas for research on air pollution, and studies are yielding valuable baseline data and basic information on the effects of air pollution. In support of the NPS Clearing the Air interpretive initiative, the Air Quality Division presents a summary of the findings of the NPS Air Quality Research and Monitoring Program.

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AIR QUALITY IN THE NATIONAL PARKS

A Summary of Findings from the National Park Service
Air Quality Research and Monitoring Program

Prepared by Energy and Resource Consultants, Inc.

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SUMMARY

The units of the National Park System contain some of the world's most spectacular scenery, unique cultural and historic resources, and diverse wildlife and vegetative communities. Millions of people visit the parks each year in search of rest, recreation, and physical and spiritual renewal. Visitors continue to be astounded and inspired by these national treasures and place a high value on knowing these resources are being protected and preserved for future generations.

Air pollution can damage and destroy the very resources and values that units of the National Park System have been created to protect and preserve. Data collected through the National Park Service (NPS) air quality research and monitoring program show that the units of the National Park System are not islands isolated from the by-products of an urban and industrial society. Manmade air pollutants are transported long distances and have been detected at all NPS monitoring sites. Air pollution effects are often subtle and insidious. Therefore, it is important that air quality and air pollution effects on park resources and values be monitored so that even slight changes can be detected.

The purpose of this report is to summarize findings from the NPS air quality research and monitoring program based on data collected through 1987. This information helps the National Park Service to remedy and prevent resource degradation so that future generations can enjoy the parks in as natural a condition as possible.

Visibility monitoring has shown that, in addition to natural sources of visibility impairment, there are varying degrees of visibility impairment from manmade pollution in virtually all monitored parks. NPS research findings suggest that fine sulfate particles are the single most important contributor to visibility impairment in most NPS units. Fine sulfate particles, which can be transported long distances in the atmosphere, are primarily the result of sulfur oxide emissions from energy and industrial sources. In the Colorado Plateau area, where Grand Canyon National Park and several other NPS units are located, fine sulfate particles are responsible for 40 to 60 percent of the visibility impairment. In eastern areas of the country, fine sulfates play an even larger role in visibility impairment. In the Pacific Northwest, sulfates are not the primary cause of visibility impairment; instead, fine carbon from controlled burning of timber and agricultural land and natural forest fires plays a prominent role.

Research on effects of visibility on the visitor experience in five NPS units indicates that clean, clear air is one of the most important features of these parks. It appears that visitors value an environment undisturbed by man above all other features of the parks. Research findings on the effects of changes in visual air quality suggest that a small increase in air pollution is more easily noticed and more disturbing to the human observer when the atmosphere is initially relatively clean.

Ambient air quality monitoring has found that ozone concentrations are high in some NPS units and even exceed National Ambient Air Quality Standards in several of these areas. These high concentrations occur not only in NPS units located near urban areas, but also in areas that are relatively remote such as

Acadia National Park. Some ozone occurs naturally, but most of the ozone in the lower atmosphere results from the photochemical reaction of manmade hydrocarbons, nitrogen oxides, and sunlight. Levels of sulfur dioxide as high as 40 percent of the short-term National Ambient Air Quality Standards are also found in some parks. It is especially significant that some injury to sensitive plant species has been documented at ozone and sulfur dioxide concentrations below the National Ambient Air Quality Standards.

Biological effects research has found ozone effects, which appear as characteristic foliar injury, on one or more species of plants and trees in virtually every park surveyed. This suggests that ozone injury is a widespread problem that even occurs at NPS units remote from urban areas. There is also evidence suggesting that reduced growth and increased mortality of some sensitive species are occurring in some of the more heavily affected areas. Research has found an apparent loss of lichens in two urban parks and effects on these sensitive plants in many parks located near sources of sulfur dioxide. Elevated levels of sulfur and heavy metals have been found in vegetation in several parks.

Information collected through the NPS air quality research and monitoring program has been used in a variety of decision-making arenas. The NPS Air Quality Division has reviewed permit applications for over 200 major industrial and energy facilities proposing to locate near NPS units to ensure that no adverse impacts to air quality related values would occur. Information regarding visibility impairment and ozone injury to vegetation in NPS units has been shared with the Congress and transmitted to the U.S. Environmental Protection Agency and state air quality control agencies to promote the development of national air pollution control programs and standards that will protect park resources. Air resource information is also shared with the public through interpretive programs and exhibits.

1.0 AIR QUALITY RESEARCH PROGRAM RESPONSIBILITIES AND ACTIVITIES

LEGISLATIVE MANDATES

In 1916, Congress enacted the National Park Service Organic Act--a law which established the National Park Service (NPS) and directed the new agency "to conserve the scenery and natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (16 U.S.C. 1). This mandate has two major objectives: (1) to protect park resources and (2) to ensure visitor enjoyment. The value of preserving scenic and natural settings has long been recognized as important for maintaining national parks, monuments, and recreation areas.

The Clean Air Act, as amended in August 1977, provides one of the most important mandates for protecting air resources in NPS areas. In section 160 of the act, Congress states that one of the purposes of the act is "to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreation, scenic, or historic value."

The Clean Air Act also establishes stringent requirements for "class I" areas, national parks over 6,000 acres and national wilderness areas over 5,000 acres that were in existence on August 7, 1977. Federal land managers (defined as the Secretaries of the Interior and Agriculture) and the federal official charged with direct responsibility for each area have been given an affirmative responsibility to protect air quality related values in these areas from adverse impacts. Air quality related values are defined by the National Park Service as "visibility and those scenic, cultural, biological, and recreation resources of an area that are affected by air quality" (43 Federal Register 15016).

Determination of an adverse impact on air quality related values requires identification of a current or potential impact and consideration of how it might affect park resources and visitor experiences. This determination combines information gathered from NPS research, information provided by a proposed new source applicant, and the federal land manager's judgment and experience about whether allowing this effect would be consistent with the National Park Service Organic Act.

The Clean Air Act also defines a national goal of remedying existing and preventing future visibility impairment in class I areas. The act requires that states incorporate measures in their state implementation plans that will ensure reasonable progress toward this goal.

SCHEMATIC OF THE AIR POLLUTION PROBLEM

In order to carry out these responsibilities, the National Park Service must understand the cause and effects of air pollution. Figure 1-1 illustrates an air pollution problem from a resource management perspective. The NPS air quality research and monitoring program addresses the following questions that are illustrated in Figure 1-1.

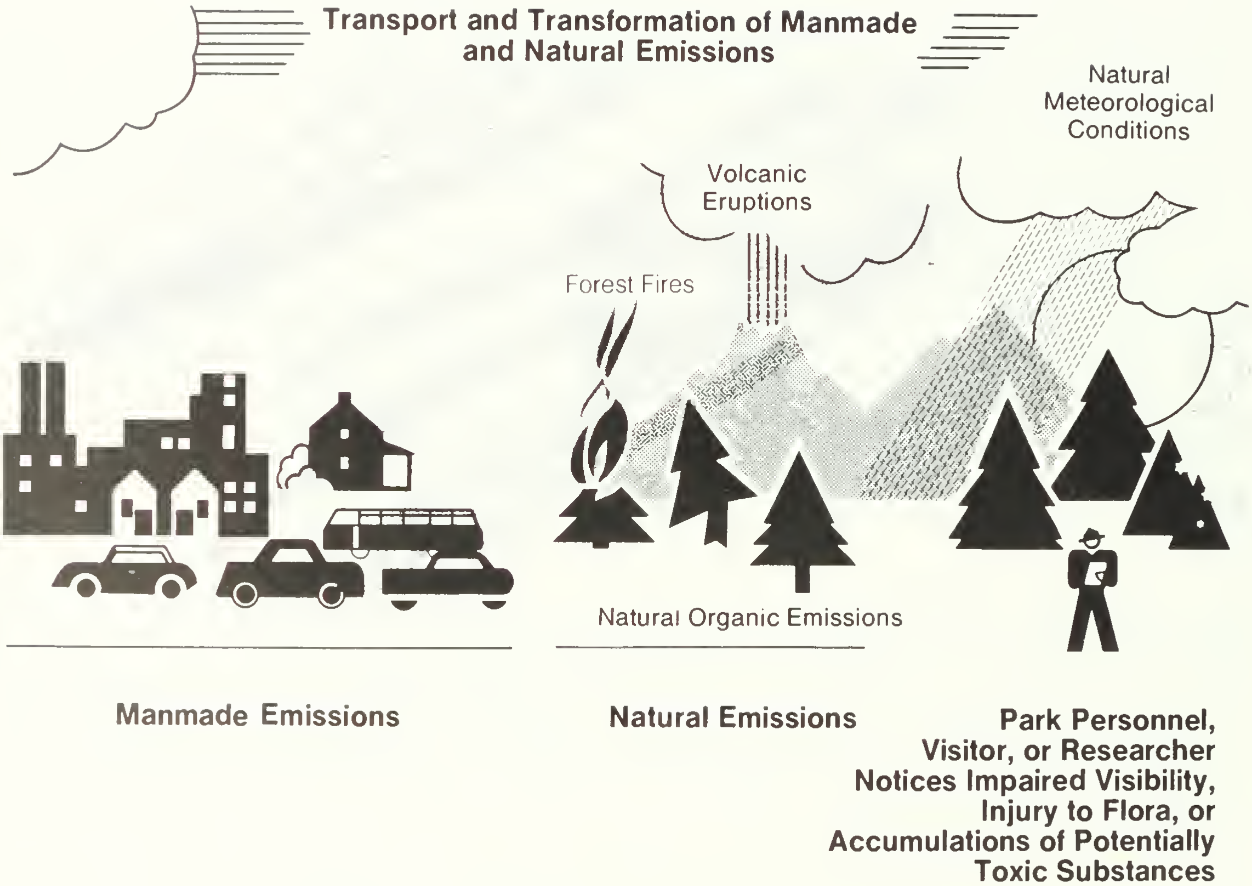


FIGURE 1-1 **Schematic of the Air Pollution Problem**

1. Is There an Identifiable Effect?

   Can park personnel, visitors, or researchers identify an effect that might be related to air pollution? The right-hand side of Figure 1-1 represents a park area where effects on resources may be noticed. Such an effect might be impaired visibility, visible injury or stunted growth of plants, or an accumulation of potentially toxic substances in the ecosystem.

2. What Might Be Causing The Effect?

   If an effect is identified, is it being caused by air pollution? This involves conducting studies in the park or in the laboratory, collecting and analyzing data on pollution levels in the air, examining plant tissue, and investigating other conditions that might be causing the observed effect.

3. Where Are the Pollutants Coming From?

   If an identified effect is being caused by air pollution, what is the source of the pollution? This includes a determination of whether or not the pollution is manmade or natural. If it is manmade, the emissions sources need to be identified and the transport and transformation of the emissions in the atmosphere need to be understood in order for the pollution effects to be reduced or eliminated.

NPS AIR QUALITY RESEARCH AND MONITORING PROGRAM

This document summarizes the findings of the NPS air quality research program which was established in 1979. Air quality research is conducted to determine the current status of air quality in the NPS units and to identify any effects air pollution is having or may have on NPS resources or visitor experiences. Air quality research is also conducted to determine sources of air pollution in the parks and the sensitivity of park resources to air pollution. The NPS air quality research program provides information needed to participate effectively in decisions that can affect the air quality in and near NPS units, and helps the National Park Service to manage air quality resources as a part of its resource protection mandate.

The NPS air quality research program involves an extensive network of monitoring for pollution, visibility conditions, and biological effects in NPS units. The monitoring program has included the following:

- Teleradiometers for measuring visibility at over 30 parks.

- Cameras for measuring visibility at over 50 parks.

- Fine particulate monitors for identifying the causes and sources of visibility impairment at over 40 parks.

- The use of biomonitors (species of plants known to be sensitive to air pollution) to identify the presence of air pollutants in several parks.

- Ozone monitors at over 30 parks for establishing baseline conditions, assisting the ozone effects research, and evaluating new pollution sources.

- Sulfur dioxide monitors at over 25 parks for establishing baseline conditions, assisting the sulfur dioxide effects research, and evaluating new pollution sources.

Air quality modeling is developed and used to study the transport and transformation of pollutants in the atmosphere. Information from the visibility monitoring network along with air quality models is used to determine the effect of manmade air pollutants on visibility at NPS units. The Park Service uses the information obtained from the air quality research and monitoring program to guide its participation in the following:

- Resource management planning within the National Park Service.

- Permit reviews concerning potential effects from increased emissions from proposed new major industrial and energy facilities outside park boundaries.

- Participation with state and local officials and industry in reaching decisions to minimize or eliminate potential impacts to the park resources and to the visitor experience.

- Reviews of environmental impact statements developed by other federal agencies concerning activities that might affect NPS units.

- Regulatory and legislative analyses.

- Development of interpretive programs for park visitors and training courses for NPS employees.

2.0 VISIBILITY

Most people have had the experience of visiting a beautiful park only to find fog, haze, or rain obscuring the scenery. In the mid-1970s Congress was made aware of the possibility that manmade pollution was affecting visibility even in remote areas of the country. In the 1977 Clean Air Act Amendments, Congress responded to this concern by establishing a national goal of remedying any existing and preventing any future manmade visibility impairment in major national parks and wilderness areas and specifically requiring consideration of visibility in efforts to prevent deterioration of air quality in clean air areas.

The preservation of unique scenic resources is very important to the National Park Service and specific vistas are often mentioned in legislation or congressional reports concerning the establishment of an NPS unit. For example, in a House report recommending establishment of Shenandoah National Park, the Southern Appalachian National Park Committee spoke of being able to see the Capitol and the Washington Monument on a clear day. Yet today, Washington, D.C. is rarely visible from Shenandoah, and there is evidence that the cause is manmade air pollution. In fact, NPS visibility monitoring has shown that in excess of 90 percent of the time scenic vistas are affected by manmade pollution at all monitoring locations within the lower 48 states. Even at Grand Canyon National Park, the color and textural detail of the canyon are nearly always impaired to some extent by manmade haze.

The NPS visibility research program was established, in part, in response to the concern that important scenic resources are being affected by air pollution or might be affected in the future. The program was also designed to provide decision makers with the tools, methods, and data needed to manage and protect visibility in the parks.

An important part of the NPS visibility research program is a visibility monitoring network which gathers information about current visibility conditions at the parks. The monitoring network also provides information about the composition of the particles in the air associated with visibility impairment. This information can be used to determine how much of the observed visibility impairment is manmade, and what types of sources emit the identified particles. Analysis of the monitoring data and research on the transport and transformation of pollutants in the air help to identify the region and sources of the manmade pollutants that cause visibility impairment. Information from the visibility research program is applied to NPS resource management decisions, and conveyed to visitors through interpretive activities. Since the Clean Air Act requires NPS involvement in certain regulatory and permitting decisions, the information is also used to promote development of programs needed to protect NPS resources. The findings of the NPS visibility research program to date are summarized in Table 2-1.

WHAT IS VISIBILITY?

Atmospheric conditions, including particles and gases in the air, determine visibility conditions which influence how easily a person can see through the air. There are several different quantitative measures of visibility conditions that characterize different aspects of these conditions.

Table 2-1. Highlights of Findings of NPS Visibility Research

CURRENT STATUS OF VISIBILITY AT NPS UNITS

- In excess of 90% of the time, scenic vistas are affected by manmade pollution at all NPS monitoring locations.
- The best visibility at monitored NPS units is in eastern Nevada, western Utah, and southern Idaho. The next best area is the Colorado Plateau region where the Grand Canyon and several other NPS units are located.
- The worst visibility at monitored NPS units is in Shenandoah and Great Smoky Mountains National Parks.
- Visual range at NPS units is typically best in winter and worst in summer when meteorological conditions are such that more pollution is transported from urban areas and industrial developments to remote areas, causing more uniform haze to occur than in the winter months.

CAUSES OF VISIBILITY IMPAIRMENT AT NPS UNITS

- Fine particles (diameter less than 2.5 microns) are generally responsible for a major share of visibility impairment at monitored NPS units.
- Fine sulfate particles are the single most important contributor to visibility impairment in NPS units except in the northwestern United States where fine carbon from manmade and natural burning plays a more prominent role. Sulfate particles are primarily the result of manmade sulfur oxide emissions.
- In the Colorado Plateau area, fine sulfate particles are responsible for 40% to 60% of the visibility impairment. In Shenandoah, fine sulfate particles appear to be responsible for over 70% of visibility impairment.
- On the average, soil-related ("crustal") material is responsible for 10% to 30% of the visibility impairment.
- Air masses containing the highest levels of sulfate particles at Grand Canyon appear to have previously passed over southern California. Air masses lowest in sulfate particles arrive at Grand Canyon from north of the park (Nevada and Utah).

Air pollution can be visible in three forms: uniform haze, layered haze, and plumes. The three photographs in Figure 2-1 illustrate uniform haze, which is a homogeneous haze that reduces visibility in every direction from the observer. The two photographs in Figure 2-2 illustrate a layered haze and a plume, respectively. Layered haze is seen as a band or bands of discoloration, with a noticeable boundary between the more polluted and the cleaner air. A plume is a band of discoloration that can typically be seen to be coming from a nearby source.

Which of these conditions might occur when pollutants are present will depend in large part on atmospheric conditions. Uniform haze occurs when the air is well mixed and pollutants are evenly distributed. A plume is formed when there is a surface wind to carry visible pollutants horizontally from an emission source into a stable atmosphere.

The difference between layered haze and uniform haze is a matter of perspective. If the observer is positioned high enough to be looking over the top of the haze, it will appear to be layered. Layered hazes are usually seen from viewpoints overlooking a valley or canyon. Layered hazes are typically associated with stable air masses where there is little mixing of the air. This occurs more often in the winter than in the summer. Layered haze can be seen some of the time at almost all parks. Recent NPS studies have found that layered hazes can be seen at Mesa Verde and Bryce Canyon National Parks on about 80 percent of the winter mornings. The condition usually does not occur in the summer, but does periodically occur in the spring and fall.

The most common measures of visibility as related to uniform haze are standard visual range, apparent contrast, light extinction, and contrast transmittance. Standard visual range, probably the most familiar measure, is the distance from an observer at which a black object just disappears against the horizon. This is a measure of how far a person can see and is one indication of how clear the air is. Apparent contrast is a measure of the contrast between the brightness of a large feature in the vista and the background sky. Light extinction is a measure of the light that is scattered and absorbed as it passes through the atmosphere and therefore does not reach an observer. More pollution in the atmosphere will cause more scattering and absorption and therefore increase the light extinction. Contrast transmittance is a measure of the ease with which the atmosphere transfers the image of the vista to the observer.

Figure 2-1 shows three forms of visibility impairment in a view at Big Bend National Park. Each photograph shows the estimated level of standard visual range, apparent contrast of the dominant distant feature, and light extinction. Note the change in color, texture, and form that accompanies the change in the visibility conditions. The ability to see color, texture, and form is what has the most effect on the observer's enjoyment of the view.

It is important to evaluate visibility conditions from the point of view of what the human observer sees. NPS research has made important contributions toward developing a measure of visibility that is appropriate for evaluating conditions in the parks. Standard visual range is a useful measure because it is easy to understand and is widely used, but it is not directly related to human visual perception and does not always reflect changes in how well an observer can see specific vista features. The results of NPS visibility

Visual Range = 340 km

Sky/Target Contrast = -.34

Light Extinction (b_{ext}) = .00149

Visual Range = 65 km

Sky/Target Contrast = -.09

Light Extinction (b_{ext}) = .00498

Visual Range = 38 km

Sky/Target Contrast = -.04

Light Extinction (b_{ext}) = .00917

FIGURE 2-1

EXAMPLES OF THE EFFECTS OF UNIFORM HAZE ON VISUAL RANGE AND CONTRAST IN A VISTA AT BIG BEND NATIONAL PARK

Layered Haze in Front of the Chuska Mountains as Viewed from Mesa Verde National Park

A Plume as Viewed from Organ Pipe Cactus National Monument

Figure 2-2

EXAMPLES OF LAYERED HAZE AND PLUME

perception research indicate that understanding the visual effects of a change in air quality requires consideration of the features of the vista as well as what is in the air, and that the most appropriate measure of visibility is one that reflects the change in color, texture, and form in a scene that is associated with a change in air quality. Contrast transmittance is a measure that meets these goals, but it has not been widely used because it is difficult to measure and is not as easy to understand as visual range.

NPS VISIBILITY MONITORING NETWORK

Visibility conditions are monitored by the National Park Service at over 50 park units throughout the United States. Figures 2-3 A and B show the locations of these NPS monitoring sites. The NPS visibility monitoring network has been growing and evolving since it was established in 1978. Most of the selected sites are at class I areas, which the Clean Air Act Amendments of 1977 singled out for special visibility protection. Some other sites were included in response to a particular visibility problem, or because visual air quality was an especially important value at those parks, or because they were situated along an important pollution transport pathway. In parks where sufficient data were collected, monitoring stations have been transferred to other NPS areas.

Special congressional appropriations in 1986 and 1987 allowed for the addition of 17 new class I sites to the network, including Arches, Badlands, Carlsbad Caverns, Haleakala, Hawaii Volcanoes, Isle Royale, Lassen Volcanic, Petrified Forest, Redwood, Virgin Islands, Voyageurs, and Yellowstone National Parks; Denali National Park and Preserve; Bandelier, Great Sand Dunes, and Pinnacles National Monuments; and Point Reyes National Seashore. Also, in 1986, 14 existing NPS class I area monitoring sites, as well as Denali National Park and Preserve, became part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) program. The IMPROVE program was established to meet regulatory requirements and is managed by a committee composed of the U.S. Environmental Protection Agency, the National Park Service, and other federal land managers. In 1988, Tonto National Monument was added to the IMPROVE network as a surrogate for a class I wilderness area managed by the U.S. Forest Service.

Figures 2-3 A and B also show that most of the monitoring is conducted in western parks. This is primarily because the weather conditions, open panoramas, and the relatively clean air typical in western parks result in long-distance views that are sensitive to small changes in air pollution.

Before 1986, the NPS visibility monitoring effort consisted of cameras which produced a photographic record of how the view changes under different weather, sunlight, and air pollution conditions; the use of teleradiometer equipment to measure visibility levels in terms of contrast; and a measurement of the particles in the air using particulate samplers and laboratory analysis. A "fully complemented" site included a camera, teleradiometer, and particulate sampler. Some sites had automatic equipment, while others required a park staff person to take photographs and/or measurements manually each day. Most of the NPS monitoring sites were fully complemented, but some had only one or two of the monitoring components, usually a camera or a camera and a particulate sampler.

FIGURE 2-3A
NPS VISIBILITY MONITORING NETWORK

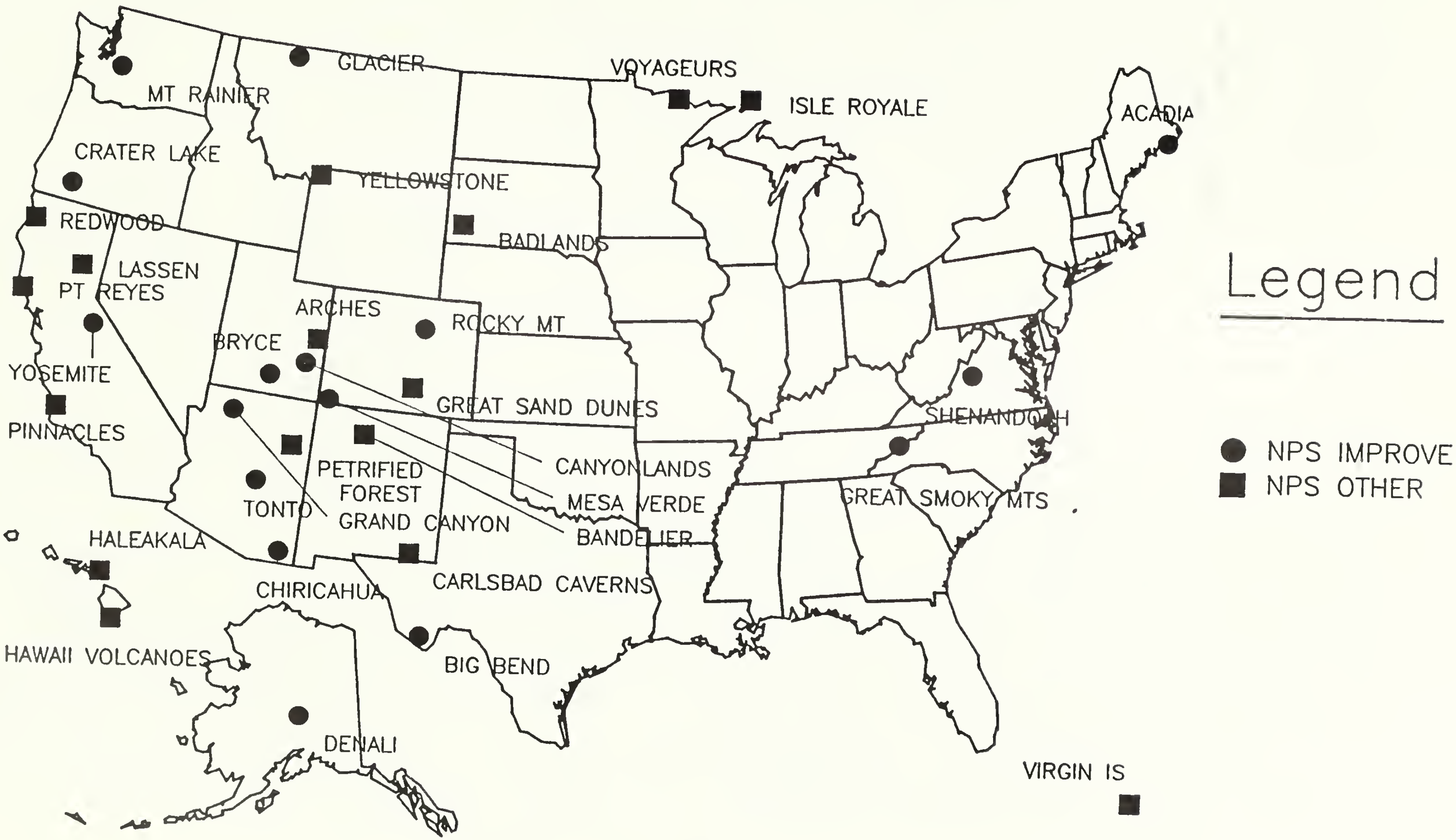
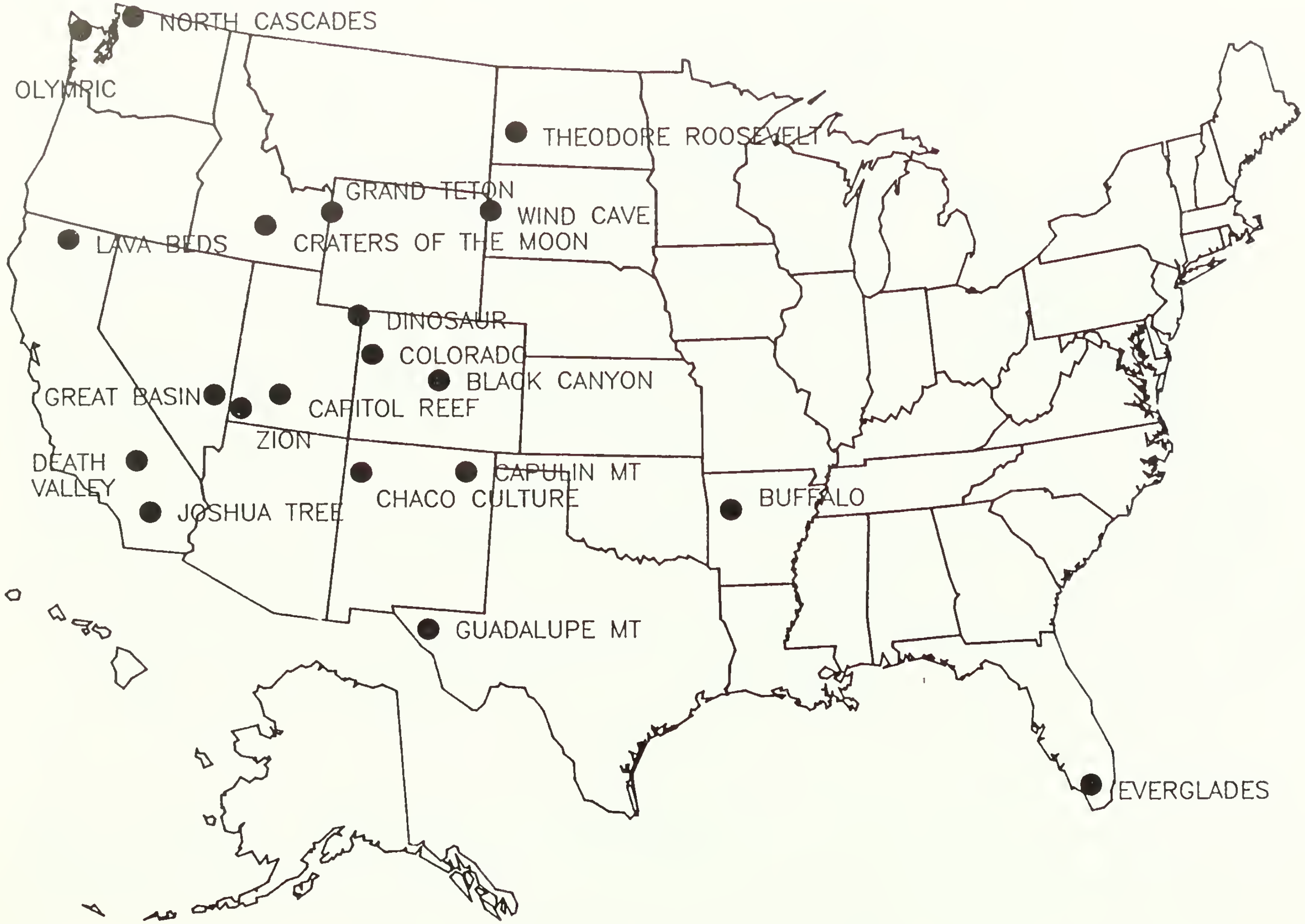


FIGURE 2-3B
NPS CAMERA-ONLY MONITORING SITES



Standard visual range estimates were derived from photographs and from the information recorded by the use of teleradiometers. Teleradiometers measured the contrast of a landscape feature against the background sky. The target was typically a dark dominant distant feature in the vista, such as a mountain, and the same target was used for each reading. Because teleradiometers needed a dark target, accurate readings were not possible if the target was covered by snow or clouds. Teleradiometers have been phased out, since techniques have been developed for determining standard visual range and contrast values directly from photographic slides. In addition the camera network has been fully automated.

Particulate samplers, which capture particles up to 15 microns in diameter are still being used at about 30 parks. However, since 1986, most particle monitors have been upgraded to allow measurement of additional visibility reducing aerosols, such as carbonaceous materials and nitrates. Particles are analyzed for elemental composition which suggests potential sources. Further analysis of visual range and particulate data helps determine the effect each pollutant has on visibility.

In 1986, the National Park Service also began deploying instruments called transmissometers that are capable of directly measuring light extinction. A fully complemented site now consists of an automatic camera, an upgraded particle monitor, and a transmissometer. The 17 new monitoring sites added in 1986 and 1987, as well as all sites in the IMPROVE network, are expected to be fully complemented.

VISIBILITY CONDITIONS AT MONITORED NPS UNITS

Although weather conditions certainly affect visibility, results from the NPS visibility monitoring network show that reduced visibility is almost always associated with the presence of particles in the air that are known to be manmade.

Differences in Visibility Levels Among NPS Units

The visual range levels described in this section are the result of a combination of manmade and natural conditions. Teleradiometer readings taken when the target is covered with snow or completely obscured by clouds are not used in the median visual range calculations, because dark-colored targets are necessary for accurate contrast measurements, but the figures reflect the effects of fog, rain, and naturally produced particles, as well as manmade pollution.

Figure 2-4 shows median standard visual range for the western United States for the summer of 1983 from June through August. The median value means that 50 percent of the time visual range is at this level or above. Summer of 1983 is used as an illustration of the typical geographical variation in visual range during the peak visitor season. Other summers generally show a similar pattern. Median visual range is approximately the same within the like-colored areas, each of which represents an increment of 20 kilometers visual range. For example, within the noncolored areas, median visual range is more than 190 and less than 210 kilometers.

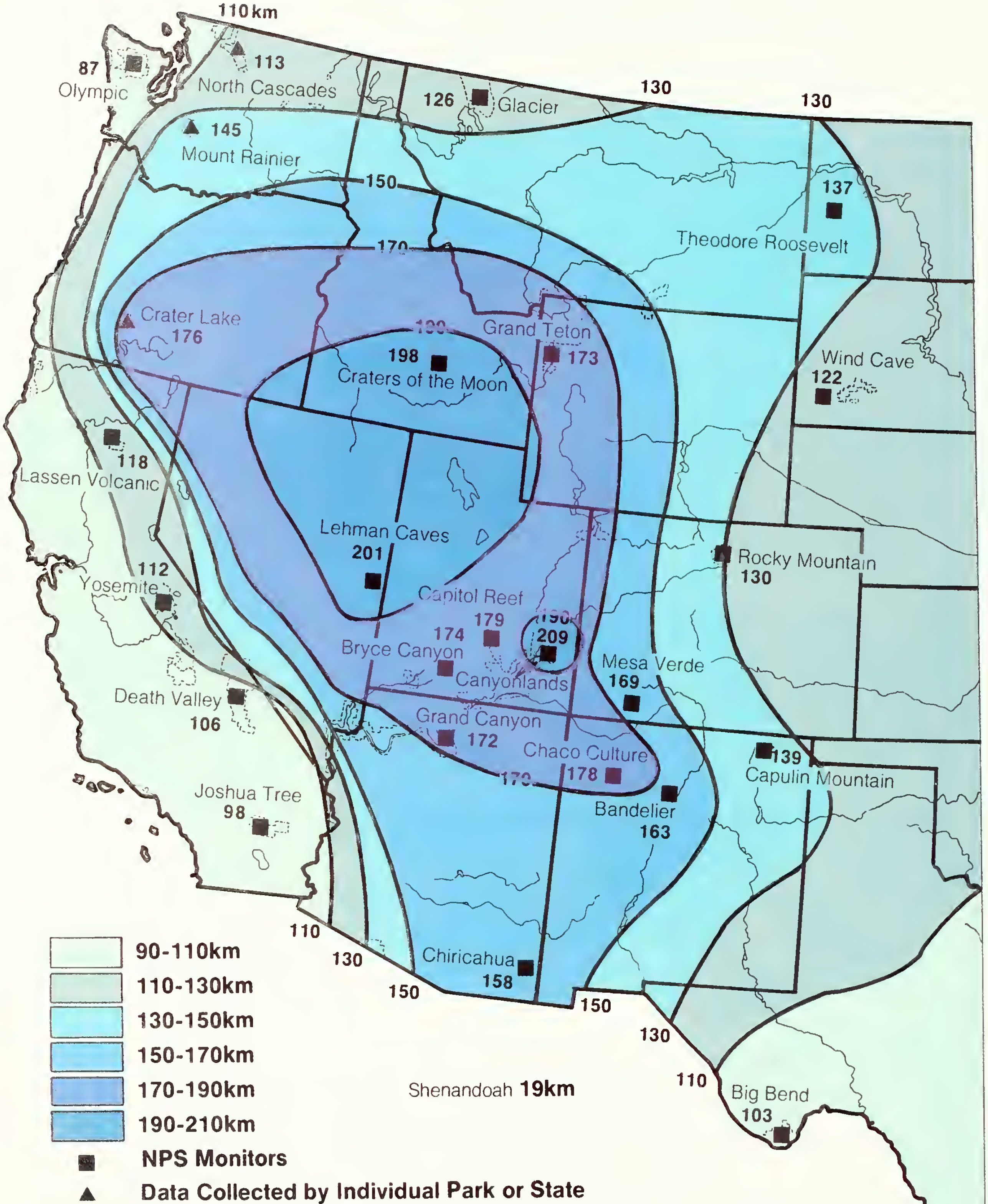


FIGURE 2-4

Isopleths of Median Visual Range over the Western United States, Summer 1983

Figure 2-4 indicates that the area with the best visibility is in Nevada, Utah, and Idaho, with a median summer visual range between 190 and 210 kilometers. The second best visibility is in the area including most of the Colorado Plateau region where several well-known NPS units (including the Grand Canyon National Park) are located. The next best visibility occurs in southern Arizona, most of New Mexico, and the Front Range area of the Rocky Mountains. The worst visibility in the western United States occurs along the coastal areas of California and Washington.

NPS research indicates that at least 50 percent of the visibility impairing particles in the air at NPS units in the Southwest, Rocky Mountain Front Range, and Great Plains areas is manmade. This is discussed in more detail in the section on causes of visibility impairment, but it is important to note that manmade pollution is a significant influence on the levels of visual range illustrated in Figure 2-4.

There are not enough NPS monitors in the East to extend this map across the entire country, but average median visual range for the same time period in Shenandoah National Park was 19 kilometers as opposed to over 100 kilometers in most western parks.

Figure 2-5 shows median visual range during the summer for the East, based on 1974-1976 data from suburban and nonurban airports. This figure is taken from a 1978 U.S. Environmental Protection Agency (EPA) report based on analysis of airport visual range data. This is not necessarily representative of visibility at NPS units but gives an idea of typical visual range levels outside of urban areas in the region. The worst visibility in the East occurs along the Mid-Atlantic Coast, the Gulf Coast, and the Ohio River Valley. The best is in northern New England. Comparing Figure 2-5 to Figure 2-4 shows that visual range in the summer months in the East is typically an order of magnitude lower than in the West.

Table 2-2 gives the median visual range for all monitored sites in the NPS network since the start of monitoring in 1978. To put these visual range figures in perspective, the theoretically best possible visual range that can be measured using a teleradiometer is about 390 kilometers. A dash indicates insufficient data and the median visual range for the season was not calculated. This occurs more often in the winter when targets are more likely to be snow-covered. The data in this table show that visual range is typically much lower in the eastern parks than in the western parks throughout the year.

Also included in Table 2-2 are the average 10th percentile and 19th percentile visual range levels for the summer season in each park over the monitored period to give an indication of the range of values typical for each park during the peak visitor season. The 10th percentile means that visual range is at that level or below 10 percent of the time. The 19th percentile means that visual range is at that level or above 10 percent of the time.

Seasonal Variation in Visual Range at NPS Units

Figure 2-6 A illustrates the typical seasonal variation (averaged over 1979-1983) in visual range at Grand Canyon National Park. Visual range is best in winter, averaging about 250 kilometers, and is worst in summer, averaging about

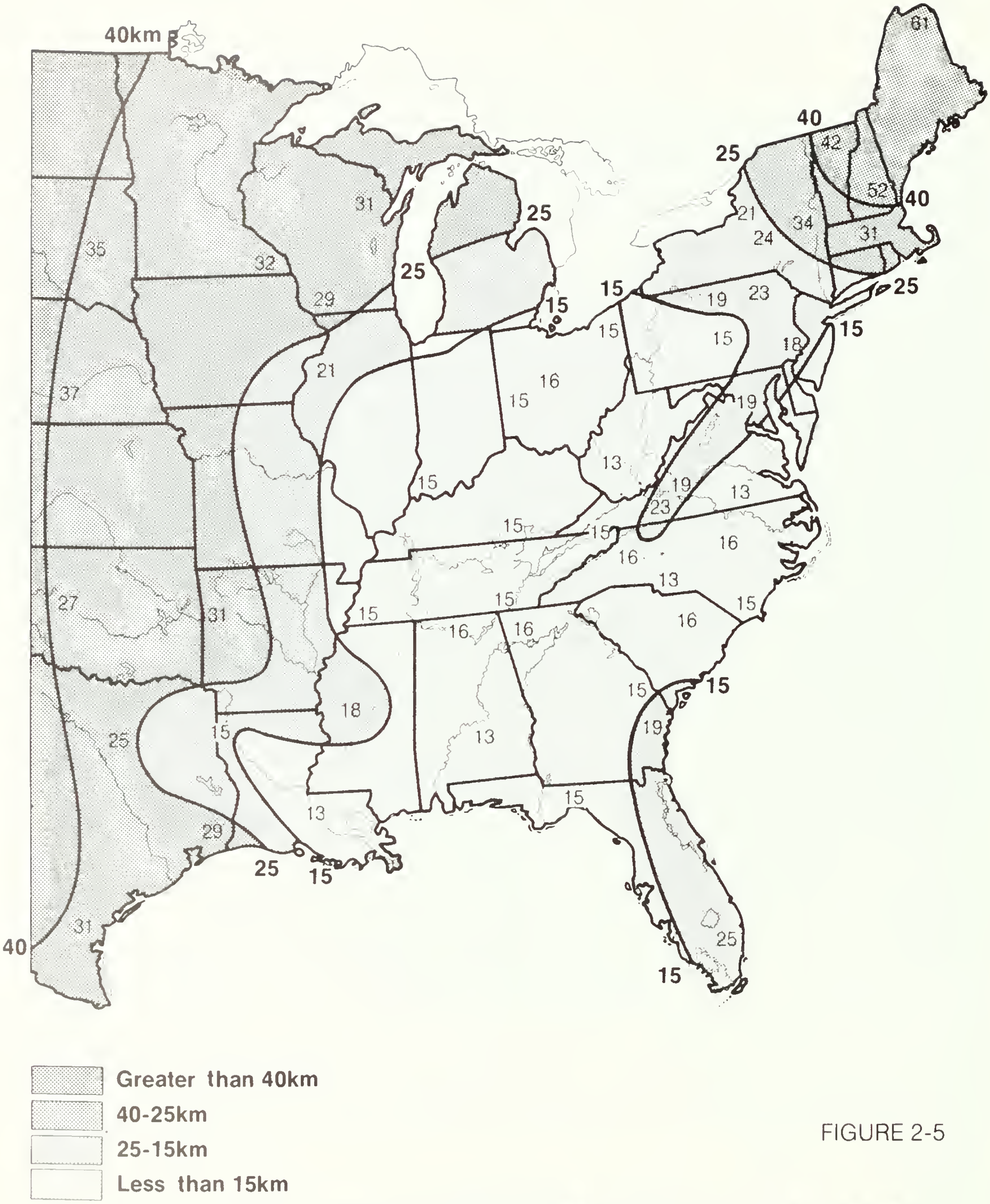


FIGURE 2-5

Median Summer Visual Range and Isopleths for Suburban/Nonurban Areas, 1974-1976 (U.S. EPA, 1979)

NPS Unit	Average Summer 10th Percentile*	Average Summer 90th Percentile**	1978 Summer	84 Fall	85 Winter	85 Spring	85 Summer	85 Fall	86 Winter	86 Spring	86 Summer	86 Fall	87 Winter
Nevada/Idaho/Utah													
Craters of the Moon NM	105	280		195	Auto	---	147	149	---	167	124	201	212
Lehman Caves NM	130	314		207	240	181	173	229	---	179	173	220	294
Colorado Plateau													
Bandelier NM			192	209	N.L.O.								
Bryce Canyon NP	133	256	180	194	215	172	174	223	---	204	187	237	310
Canyonlands NP	131	290		268	---	183	198	---	---	---	233	198	267
Capitol Reef NP	113	258	174	196	210	145	148	---	---	---	188	195	215
Chaco Culture NHP	136	259		245	283	215	200	246	---	---	175	212	237
Colorado NM	122	286		193	167	218	179	211	203	209	167	282	---
Dinosaur NM	105	277	207	206	138	121	154	208	188	190	0	0	0
Grand Canyon NP	114	252		180	247	176	160	211	---	199	174	259	258
Mesa Verde NP	125	246	---	209	---	200	175	216	261	190	0	0	0
Navajo NM			191										
White Sands NM													
Wupatki NM											0	0	0
Zion NP													
Southwest Desert													
Big Bend NP	68	248	133	152	---	167	145	170	---	110	155	197	153
Carlsbad Caverns NP	94	249									136	228	241
Chiricahua NM	94	232		158	204	179	130	193	---	---	0	0	0
Guadalupe Mtns. NP	91	231		145	173	144	117	166	202	144	108	169	188
Joshua Tree NM	76	250		---	---	150	76	159	215	146	103	152	271
Rocky Mountains													
Capulin Mtn. NM	93	224		186	---	172	136	216	---	---	0	0	0
Glacier NP	71	265		123	---	---	139	114	---	169	164	209	74
Grand Teton NP	99	251		157	200	---	0	0	0	0	0	0	0
Rocky Mountain NP	72	269		190	---	156	---	209	---	161	163	214	263
Yellowstone NP													
Great Plains													
Buffalo NR	17	115			66	64	49	43	67	41	58	63	---
T. Roosevelt NP	81	237		223	---	181	172	---	---	138	140	197	283
Wind Cave NP	81	230		200	---	178	150	0	0	---	0	0	0
Central California													
Death Valley NM	66	183		177	---	132	81	168	259	---	---	---	0
Yosemite NP	47	148		33	51	69	---	---	---	109	73	91	154
Pacific Northwest													
Crater Lake NP***	89	248					156	220	---	---	137	148	235
Lava Beds NM				187	199	162	184	200	---	---	0	0	0
Lassen Volcano NP	121	284											
Mount Rainier NP***					---	---	146	152	---	163	126	170	279
North Cascades NP***											146	163	
Olympic NP	49	191		94	95	97	134	105	119	79	141	147	106
East													
Acadia NP	42	181		104	82	105	---	---	97	96	94	106	123
Everglades NP													
Great Smoky Mtns. NP				69	48	60	37	59	80	72	29	51	118
Shenandoah NP	10	77		42	---	43	36	43	---	29	28	52	---

* The 10th percentile means that visual range
available data.

** The 90th percentile means that visual range
with available data.

*** North Cascades, Mount Rainier and Crater L
here for Crater Lake were collected and anal
data for Mt. Rainier and North Cascades are
photographs were not always taken everyday

Auto. This site is now using automated equipment

N.L.O. This site is no longer operating.

--- There are not sufficient data available for th
done in some parks.

0 Insufficient data to calculate inherent contra

Table 2-2. Visual Range at NPS Visibility Monitoring Sites
Summer 1978 – Fall 1984

Median Visual Range Each Season (Summer 1978 – Fall 1982)

NPS Unit	Average Summer 10th Percentile*	Average Summer 90th Percentile**	1978 Summer	1978 Fall	79 Winter	79 Spring	79 Summer	79 Fall	80 Winter	80 Spring	80 Summer	80 Fall	81 Winter	81 Spring	81 Summer	81 Fall	82 Winter	82 Spring	82 Summer	82 Fall
Nevada/Idaho/Utah																				
Craters of the Moon NM	105	280																	170	196
Lehman Caves NM	130	314																	188	215
Colorado Plateau																				
Bandelier NM			192	168	250	---	158	162	196	188	176	177	220	186	146	178	207	190	166	221
Bryce Canyon NP	133	256	180	215	266	147	167	185	297	146	135	213	283	185	148	193	274	160	159	195
Canyonlands NP	131	290		204	---	175	189	189	191	181	186	201	---	161	158	193	204	199	176	217
Capitol Reef NP	113	258	174	196	---	---	161	165	---	149	154	176	---	164	147	182	212	189	160	206
Chaco Culture NHP	136	259		204	249	---	183	198	---	170	171	196	236	174	146	201	233	208	177	210
Colorado NM	122	286									---	209	254	189	172	187	223	N...O.		
Oinosaur NM	105	277	207	---	---	---	185	198	---	---	156	215	219	188	139	---	---	---	---	---
Grand Canyon NP	114	252		194	235	147	172	188	277	125	150	185	234	154	121	180	259	158	153	200
Mesa Verde NP	125	246	---	188	---	---	184	187	---	---	167	191	202	175	143	157	241	176	162	178
Navajo NM			191	188	---	153	158	169	---	145	161	202	227	170	140	199	241	156	155	173
White Sands NM				138	214	158	126	171	125	117	132	174	134	105	123	158	N.L.O.			
Wupatki NM							154	158	236	144	151	169	155	154	136	167	186	140	141	154
Zion NP															Data will not be reported					
Southwest Desert																				
Big Bend NP	68	248	133	119	198	146	137	119	150	131	117	125	181	152	112	123	186	138	139	137
Carlsbad Caverns NP	94	249		169	248	---	139	139	199	200	N.L.O									
Chiricahua NM	94	232													99	152	228	188	139	196
Guadalupe Mtns. NP	91	231															175	139	129	150
Joshua Tree NM	76	250																	113	160
Rocky Mountains																				
Capulin Mtn. NM	93	224									132	176	239	153	134	176	253	180	140	179
Glacier NP	71	265																127	---	---
Grand Teton NP	99	251									158	158	---	---	136	139	128	156	127	172
Rocky Mountain NP	72	269									121	144	184	132	124	122	169	132	118	127
Yellowstone NP															136	124	184	148	---	N.L.O.
Great Plains																				
Buffalo NR	17	115																		
T. Roosevelt NP	81	237				121	113	152	207	102	131	175	179	123	107	124	122	152	122	160
Wind Cave NP	81	230				115	143	164	---	105	147	154	229	138	123	101	---	199	123	169
Central California																				
Oeath Valley NM	66	183							239	114	93	167	233	130	85	151	214	141	110	186
Yosemite NP	47	148																		128
Pacific Northwest																				
Crater Lake NP***	89	248													134	152			135	161
Lava Beds NM																				Data not yet available
Lassen Volcano NP	121	284																	143	187
Mount Rainier NP***																				
North Cascades NP***																				
Olympic NP	49	191									---	---	---	---	---	67	---	---	65	113
East																				
Acadia NP	42	181											43	66	73	92	76	86	75	92
Everglades NP																				
Great Smoky Mtns. NP																				
Shenandoah NP	10	77								41	26	52	---	28	26	67	---	---	17	38

Median Visual Range Each Season (Winter 1983 – Winter 1987)

NPS Unit	83 Winter	83 Spring	83 Summer	83 Fall	84 Winter	84 Spring	84 Summer	84 Fall	85 Winter	85 Spring	85 Summer	85 Fall	86 Winter	86 Spring	86 Summer	86 Fall	87 Winter
Nevada/Idaho/Utah																	
Craters of the Moon NM	---	---	198	164	---	---	154	195	Auto	---	147	149	---	167	124	201	212
Lehman Caves NM	---	324	201	213	323	205	193	207	240	181	173	229	---	179	173	220	294
Colorado Plateau																	
Bandelier NM	319	228	163	185	225	179	166	209	N.L.O.								
Bryce Canyon NP	229	169	174	204	217	201	189	194	215	172	174	223	---	204	187	237	310
Canyonlands NP	---	170	209	264	---	184	231	268	---	183	198	---	---	---	233	198	267
Capitol Reef NP	274	224	179	212	138	189	223	196	210	145	148	---	---	---	188	195	215
Chaco Culture NHP	---	170	178	201	253	201	202	245	283	215	200	246	---	---	175	212	237
Colorado NM						178	187	193	167	218	179	211	203	209	167	282	---
Oinosaur NM	---	---	---	---	121	92	178	206	138	121	154	208	188	190	0	0	0
Grand Canyon NP	250	180	172	184	260	131	137	180	247	176	160	211	---	199	174	259	258
Mesa Verde NP	---	187	169	188	189	183	167	209	---	200	175	216	261	190	0	0	0
Navajo NM	N.L.O.																
White Sands NM															0	0	0
Wupatki NM	N.L.O.																
Zion NP																	
Southwest Desert																	
Big Bend NP	204	148	103	120	212	144	127	152	---	167	145	170	---	110	155	197	153
Carlsbad Caverns NP															136	228	241
Chiricahua NM	208	194	158	159			143	158	204	179	130	193	---	---	0	0	0
Guadalupe Mtns. NP	211	143		139	191	140	133	145	173	144	117	166	202	144	108	169	188
Joshua Tree NM	148	139	98	116	207	156	---	---	---	150	76	159	215	146	103	152	271
Rocky Mountains																	
Capulin Mtn. NM	250	172	139	174	247	154	151	186	---	172	136	216	---	---	0	0	0
Glacier NP	---	126	103	---	---	140	123	123	---	---	139	114	---	169	164	209	74
Grand Teton NP	167	154	173	199	178	162	181	157	200	---	0	0	0	0	0	0	0
Rocky Mountain NP	88	75	130	164	213	148	140	190	---	156	---	209	---	161	163	214	263
Yellowstone NP																	
Great Plains																	
Buffalo NR			25	48	82	88			66	64	49	43	67	41	58	63	---
T. Roosevelt NP	170	116	137	163	176	153	167	223	---	181	172	---	---	138	140	197	283
Wind Cave NP	---	118	122	177	216	162	137	200	---	178	150	0	0	---	0	0	0
Central California																	
Oeath Valley NM	282	155	106	179	234	137	104	177	---	132	81	168	259	---	---	---	0
Yosemite NP	111	118	112	---	62	54	39	33	51	69	---	---	---	109	73	91	154
Pacific Northwest																	
Crater Lake NP***			176				145				156	220	---	---	137	148	235
Lava Beds NM							174	187	199	162	184	200	---	---	0	0	0
Lassen Volcano NP	---	104	118	140	N.L.O.												
Mount Rainier NP***			145				168		---	---	146	152	---	163	126	170	279
North Cascades NP***			113				165								146	163	
Olympic NP	69	77	87	100	138	78	98	94	95	97	134	105	119	79	141	147	106
East																	
Acadia NP				Auto.	92	90	79	104	82	105	---	---	97	96	94	106	123
Everglades NP				Auto.													
Great Smoky Mtns. NP				Auto.	82	62	43	69	48	60	37	59	80	72	29	51	118
Shenandoah NP	---	60	19	51	---	37	25	42	---	43	36	43	---	29	28	52	---

* The 10th percentile means that visual range is this low or lower 10% of the time. This is an average 10th percentile for all summers with available data.

** The 90th percentile means that visual range is this high or lower 90% of the time. This is an average 90th percentile for all summers with available data.

*** North Cascades, Mount Rainier and Crater Lake are now official NPS visibility monitoring sites, but the 1983 and 1984 data reported here for Crater Lake were collected and analyzed by the State of Oregon, Oepartment of Environmental Quality. The 1983 and 1984 data for Mt. Rainier and North Cascades are not strictly comparable to the data for the other parks in the network because photographs were not always taken everyday, and may overstate the visual range relative to the other parks.

Auto. This site is now using automated equipment for which data analysis procedures have not yet been finalized.

N.L.O. This site is no longer operating.

--- There are not sufficient data available for this season to calculate median visual range. Monitoring is not done in some parks.

0 Insufficient data to calculate inherent contrast.

150 kilometers. A similar pattern of best visual range in winter and worst in summer can be observed at most parks listed in Table 2-2.

The reason for this seasonal pattern is believed to be that the air is typically more stable in the winter allowing for less transport of air pollution from areas of high emissions, such as cities and industrial sites, to remote areas where parks are located. In winter there is a more frequent occurrence of temperature inversions, and stable air masses tend to trap emissions in urban and industrial areas. (A temperature inversion occurs when the air closest to the ground is colder than the air above it. The warmer air acts as a lid keeping the colder air and the emissions in it close to the ground.) In summer there is more mixing and transport of air masses and pollution emissions so that urban and industrial areas are typically more clear and remote areas are less clear than in the winter. Exceptions to the pattern of high winter and low summer visual range at a park occur more often if an urban or industrial pollution source is located nearby.

Figures 2-6 B and C provide supporting evidence that seasonal differences in long-distance transport of pollutants are partially responsible for the seasonal variation in visual range. Figure 2-6 C shows the seasonal average amount of fine particles in the air at Grand Canyon National Park. These are manmade and naturally emitted particles that can be transported long distances in the atmosphere. Fine sulfur is one type of fine particle that is known to be the result of manmade emissions. Seasonal averages for fine sulfur at Grand Canyon are shown in Figure 2-6 B. The total fine mass and fine sulfur mass are highest in the summer and lowest in the winter, suggesting that these particles are contributing to the seasonal pattern of visual range.

Figure 2-6 D shows that coarse mass is also highest in summer and lowest in winter. Coarse mass is made up of large particles such as wind-blown dust that are not transported long distances due to their size. They are the result of natural and manmade activity and are highest in summer probably because there is less moisture in the soil allowing particles to be more easily entrained by surface winds. Figure 2-6 D suggests that seasonal differences in coarse mass also contribute to the seasonal pattern of visual range observed at Grand Canyon.

Although coarse and fine mass have the same seasonal variation at Grand Canyon, this trend does not hold at all monitoring sites. Coarse mass tends to be dependent on local terrain and meteorological conditions. For instance, at Big Bend National Park coarse mass is highest during spring and fall and lowest during summer months. Since Big Bend is quite dry year-round, coarse mass concentrations reflect seasonal wind conditions.

Year-to-Year Variation in Visual Range in NPS Units

The year-to-year variation in median summer and median fall visual range is illustrated in Figure 2-7 for nine parks in eight different geographical areas. Two seasons are shown because the year-to-year variation is somewhat different for each season. Summer and fall were selected because more complete data are available for these seasons than for winter and spring when snow cover is more common. A park with the most available years of data was selected for each of the geographical groupings that were used in Table 2-2.

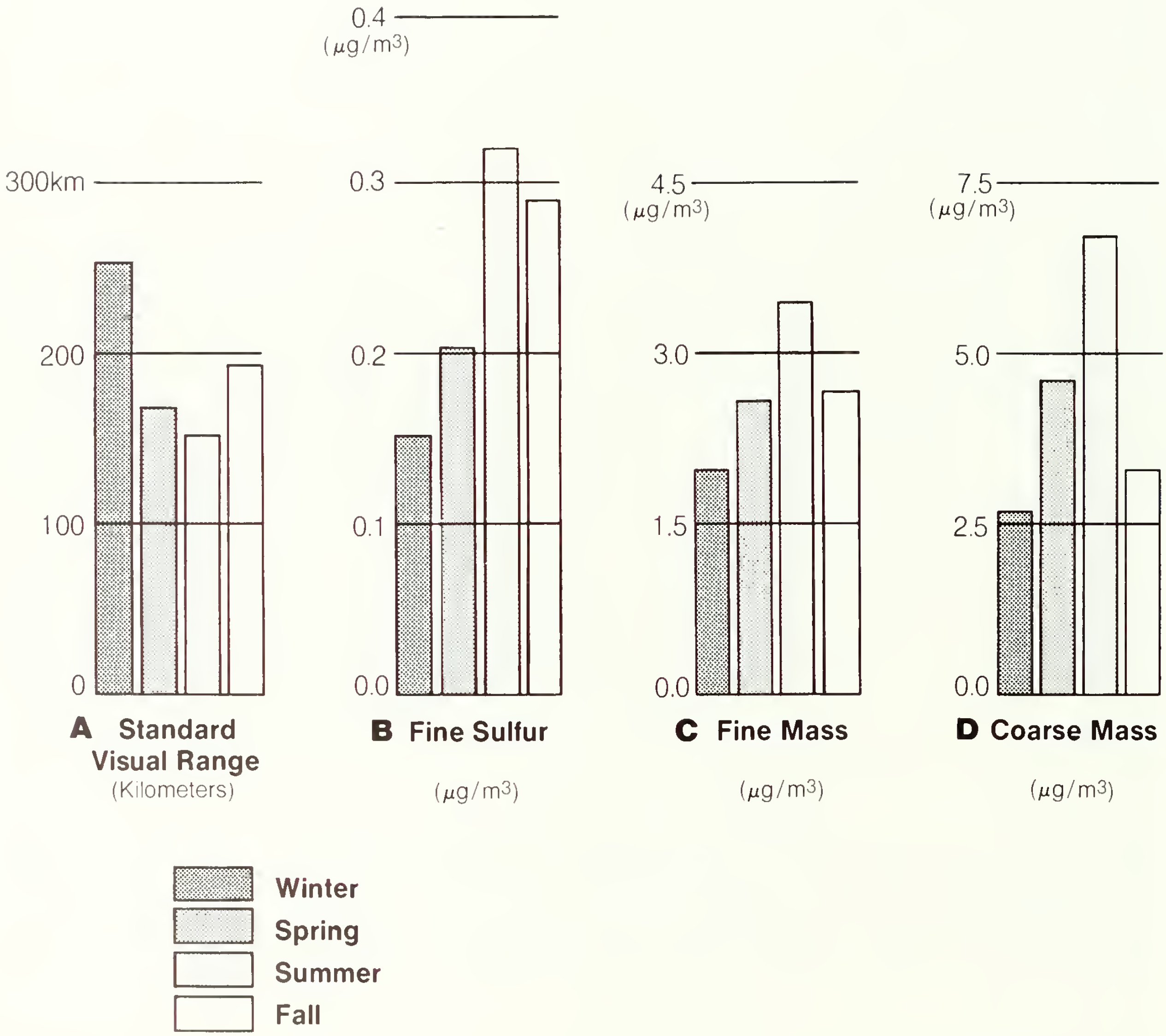


FIGURE 2-6 A. B. C. D.

Seasonal Average Standard Visual Range, Fine Sulfur, and Fine and Coarse Mass Concentrations, at Grand Canyon from 1979 to 1983

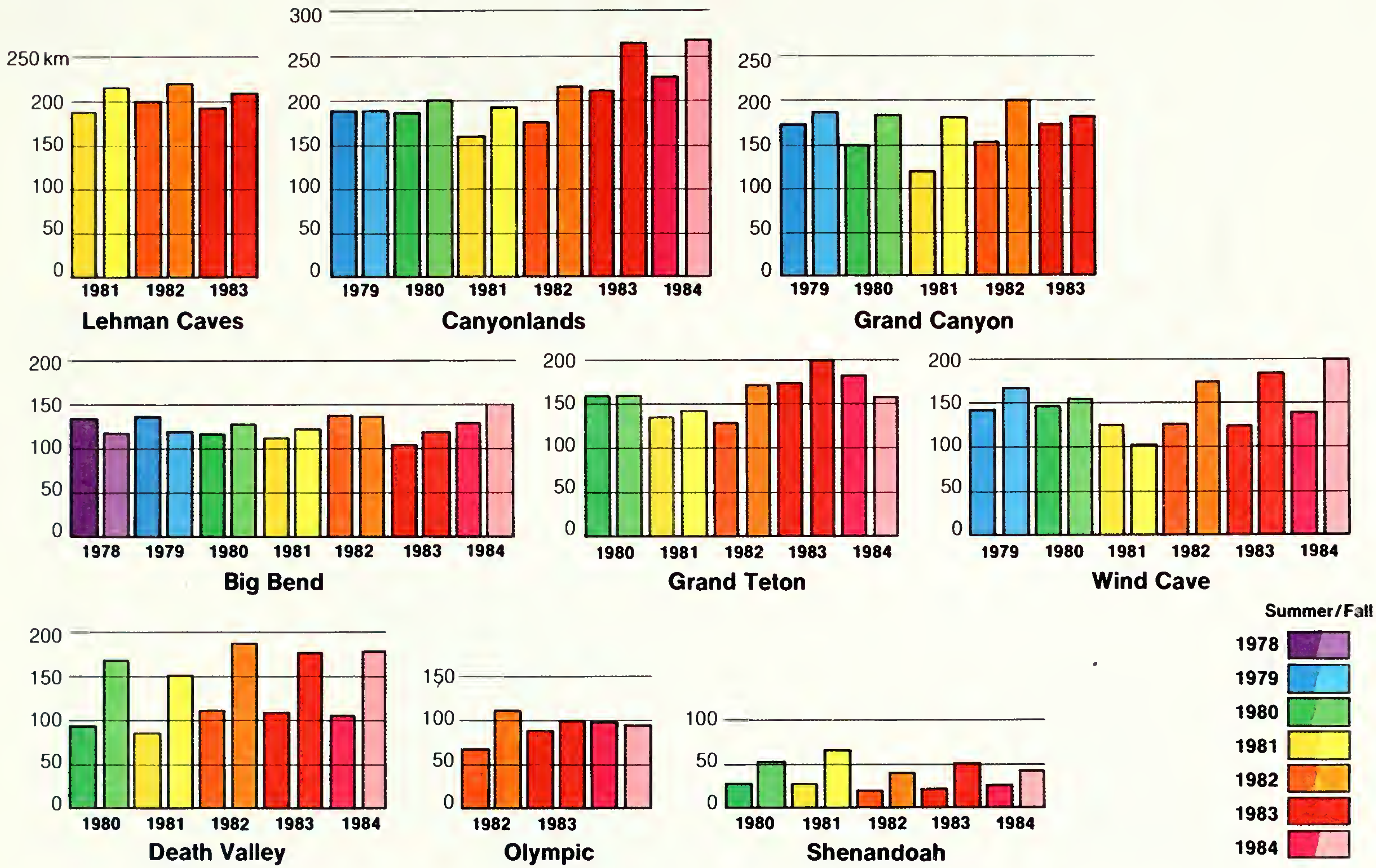


FIGURE 2-7 **Year-to-Year Variation in Median Visual Range for Summer and Fall in Kilometers**

Two parks from the Colorado Plateau area were included to show that the same pattern applied to both. Canyonlands and Grand Canyon National Parks show a similar pattern in summertime visual range with a decline to 1981 and an increase to 1983 and 1984. Fall visual range levels at both parks show a somewhat different pattern from the summertime variation. In the Southwest Desert area, visual range at Big Bend National Park shows little variation in summer or fall levels. Little variation is apparent in the Great Plains area at Wind Cave National Park.

None of these parks shows a clear improvement or deterioration in visual range over this time period, but 3 to 7 years of data are considered insufficient to average out the effects of year-to-year meteorological variation. A few more years of data and more analysis of emissions and transport will be needed to determine if the contributions of manmade air pollution to visibility impairment in the NPS units are changing or remaining the same over the long term.

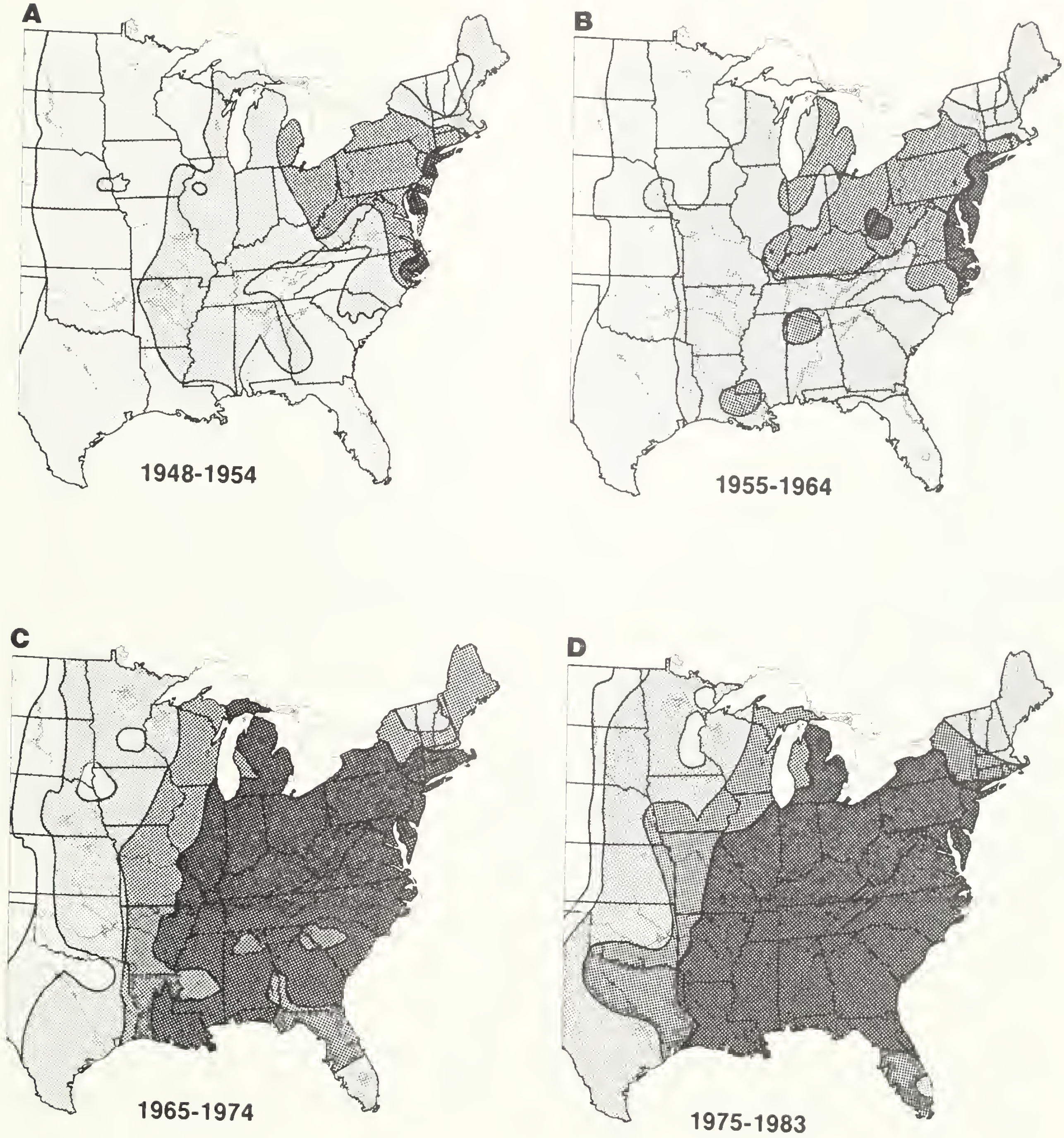
Historical Trends in Visual Range Outside the National Park System

Airport visual range data from the 1940s through the 1970s provide some information about long-term visibility trends throughout the country. Airports are typically located close to populated areas so visibility there may not be representative of visual range in national parks, but these data do provide relevant information. Studies using these data to analyze historical trends in visual range are summarized in the 1979 U.S. Environmental Protection Agency report to Congress, "Protecting Visibility," and in the 1985 U.S. Environmental Protection Agency Visibility Task Force report "Developing Long-Term Strategies for Regional Haze." The historical trends in visibility presented in these studies indicate that manmade pollution has contributed to a general decline in visual range in many parts of the country over the last several decades, especially in nonurban areas and in the summer, suggesting that NPS units may have been affected. Summer trends are especially important because the summer is the peak visitation period for most national parks.

The airport visual range studies show that summer visibility conditions in the East have deteriorated dramatically from the 1940s to the 1970s. Figure 2-8 shows the decline in average summer visual range in the East over the period 1948 to 1983. The authors note that the scales chosen for this figure mask a modest improvement in visibility in some areas of the southeastern United States since 1972. Visual range during the cool seasons showed some improvement in the northeastern region and significant deterioration in the Gulf Coast region over this period. The overall result was that by the early 1970s summer became and has remained the season with the poorest visibility in the East.

This decline in summer visibility has been correlated with a change in the seasonal pattern of electricity production. In the 1950s there was a clear peak in production during the winter with lower levels throughout the rest of the year. By the 1970s electricity production showed two peaks in the year, one in the winter and one in the summer. While this does not prove that the deterioration in the summer visibility is a result of manmade pollution, it is strong circumstantial evidence.

Studies that have examined differences between airport visual range trends in urban areas and in suburban/nonurban areas have found a significant decline in



Greater than 52km
39-52km
31-39km
26-31km
Less than 26km

FIGURE 2-8

Spacial Distribution of Average Airport Visual Range in the Eastern United States During Summer from 1948 to 1983 (U.S. EPA 1985)

visual range in suburban/nonurban areas, while visual range in urban areas has stayed about the same or improved slightly. This has been found in the East and in California and suggests that reduced visual range has changed from a local to a regional phenomenon.

Analysis of airport visual range data in the Rocky Mountain Southwest shows a deterioration of about 10 to 30 percent from the mid-1950s to the early 1970s and a slight improvement (5 to 10 percent) into the mid-1970s. This improvement occurred especially at sites in or near Arizona and coincided with a reduction in emissions from Arizona copper smelters which occurred during that period due to a shut down in their operations.

CAUSES OF VISIBILITY IMPAIRMENT AT NPS UNITS

Understanding what causes changes in visibility conditions is essential if the National Park Service is to protect visibility in the parks now and in the future. Analysis of the particulate data from the NPS visibility monitoring network suggests possible sources of air pollution associated with visibility impairment.

In the absence of manmade pollution, visibility is limited by the light scattering of air molecules and naturally occurring aerosols such as water droplets and wind-blown dust. Aerosols are small solid or liquid particles suspended in the air. Some are emitted directly and many are formed by the atmospheric reaction of natural and/or manmade gaseous emissions.

Relative Effects of Different Particles on Visibility

Aerosols scatter light to different degrees, depending on their size, and are the primary cause of haze in the atmosphere. Because different size particles reduce visibility with varying degrees of efficiency, it does not necessarily follow that an aerosol species making up a certain fraction of the total mass of aerosols in the atmosphere will be responsible for that same fraction of visibility reduction. In fact, fine aerosols, particularly those with diameters between 0.2 and 1.0 micron (less than one-tenth the diameter of a fine human hair), are the most efficient at scattering light and therefore cause a larger fraction of visibility reduction than their fraction of total mass. Coarse particles, with diameters of 2.5 to 15 microns, also contribute to visibility impairment, but not in proportion to their fraction of total mass. For example, coarse particles typically make up about 60 percent of total particulate mass at the Grand Canyon National Park and other parks in the southwestern United States, but typically cause only about 20 percent of the visibility reduction, because they do not reduce visibility as much as smaller particles.

Special attention has been given to fine sulfate particulates, which almost entirely come from manmade emissions of sulfur oxides. Fine sulfate particles most commonly occur in the form of ammonium sulfate particles that are particularly efficient at scattering light due to their size.

Preliminary research suggests that fine particles at Grand Canyon are typically about one-third sulfate, but sulfates usually cause about two-thirds of all the

visibility impairment. The amount of fine sulfate particles present in the atmosphere may therefore be an important indication of the extent of manmade visibility impairment.

Composition of Particulates at NPS Units

Table 2-3 shows the average coarse, fine, and total particulate mass measured at NPS monitoring sites for June 1982 to November 1983. One-half to two-thirds of the total particulate mass is made up of coarse particles at most of the NPS sites. An exception is Shenandoah National Park where a higher percentage of total mass is made up of fine particles. Because NPS studies have shown that fine particles are responsible for more visibility impairment than coarse particles, even though coarse particles make up more of the total particulate mass in the air, NPS research has emphasized analysis of the composition of the fine particles measured at NPS monitoring sites.

Table 2-4 gives the five categories of fine particles used in the analysis and lists the sources of each type of particle. In this analysis, all the sulfate particles are presumed to be ammonium sulfate. Since this is the most common form, this provides an acceptable approximation. Nitrates are another aerosol that results from manmade emissions, in this case emissions of nitrogen oxides. These are included in the "other" category.

Figure 2-9 shows the average composition of fine particles at four NPS monitoring sites for June 1982 through November 1983. Each site is in a different geographical region and the differences between them are indicative of the differences between these regions. The diameter of each circle is proportional to the total mass of fine particles typical for each park.

In the East, fine particles at Shenandoah National Park are almost 60 percent ammonium sulfates. This means that more than half of the fine particles in this area are the result of manmade emissions. Soil and smoke make up a fairly small percentage of all fine particles at Shenandoah. The total amount of fine particles is highest at Shenandoah relative to the other three parks shown.

In the Great Plains, about one-third of the fine particles at Theodore Roosevelt National Park are ammonium sulfates. Soil and smoke make up a higher percentage of fine mass than at Shenandoah, but less than at the other western sites.

In the Colorado Plateau area, fine particles at Grand Canyon National Park are also about one-third ammonium sulfate. Smoke and soil combined make up about another one-third, which is a higher percentage than at Shenandoah and Theodore Roosevelt. The total amount of fine particles is smallest at Grand Canyon relative to the other three parks shown.

In the Southwest Desert area, fine particles at Big Bend National Park are more than one-third ammonium sulfate. Soil is a large component relative to the other sites, making up about one-fourth of all fine particles. Smoke is about 6 percent of fine particles, similar to the percentage at Theodore Roosevelt National Park.

Table 2-3. Average Particulate Mass at NPS Monitoring Sites
June 1982 to November 1983

	Coarse		Fine		Total
	Mass	% of Total	Mass	% of Total	Mass
	(microgram per cubic meter)				
Craters of the Moon	6.4	63%	3.7	37%	10.1
Lehman Caves	4.3	62%	2.6	38%	6.9
Arches	9.7	68%	4.6	32%	14.3
Bandelier	5.8	57%	4.4	43%	10.2
Bryce Canyon	4.7	62%	2.9	38%	7.6
Canyonlands	8.0	70%	3.5	30%	11.5
Chaco Culture	7.1	65%	3.8	35%	10.9
Dinosaur	8.4	68%	4.0	32%	12.4
Grand Canyon	4.9	60%	3.2	40%	8.1
Mesa Verde	3.9	53%	3.5	47%	7.4
Big Bend	9.2	61%	6.0	39%	15.2
Chiricahua	6.6	58%	4.8	42%	11.4
Guadalupe Mountains	8.7	65%	4.7	35%	13.4
Joshua Tree	7.3	62%	4.5	38%	11.8
Tonto	8.7	62%	5.3	38%	14.0
Capulin Volcano	5.6	62%	3.5	38%	9.1
Glacier	5.0	49%	5.3	51%	10.3
Grand Teton	3.2	37%	5.5	63%	8.7
Rocky Mountain	4.6	57%	3.5	43%	8.1
Theodore Roosevelt	8.6	65%	4.6	35%	13.2
Wind Cave	6.4	60%	4.3	40%	10.7
Death Valley	9.6	65%	5.2	35%	14.8
Lassen Volcanic	4.2	56%	3.3	44%	7.5
Yosemite	5.1	49%	5.4	51%	10.5
Crater Lake	3.4	51%	3.3	49%	6.7
Lava Beds	3.5	51%	3.4	49%	6.9
Mount Rainier	7.2	56%	5.7	44%	12.9
Shenandoah	5.7	36%	10.1	64%	15.8

Table 2-4. Categories of Fine Particulates

Fine Particulate Category	Definition	Common Sources
Ammonium sulfates	Aerosols formed in the atmosphere as a result of sulfur oxide emissions	• Power plants • Smelters • Oil and gas fields • Refineries • Industrial boilers
Smoke	Soot and organic material emitted from open burning	• Prescribed forest burning • Natural forest fires • Agricultural burning • Wood stoves and fireplaces
Soil	Fine particles of wind-blown dust	• Wind/ground • Surface mining • Construction • Traffic on dirt roads
Metal	Fine metal particles such as copper, lead, and zinc	• Industrial processing • Mining • Soil • Smelter operations • Motor vehicles
Other	Nitrates and organic aerosols and undefined fine aerosols	• Power plants • Motor vehicles • Refineries • Vegetation • Combustion processes

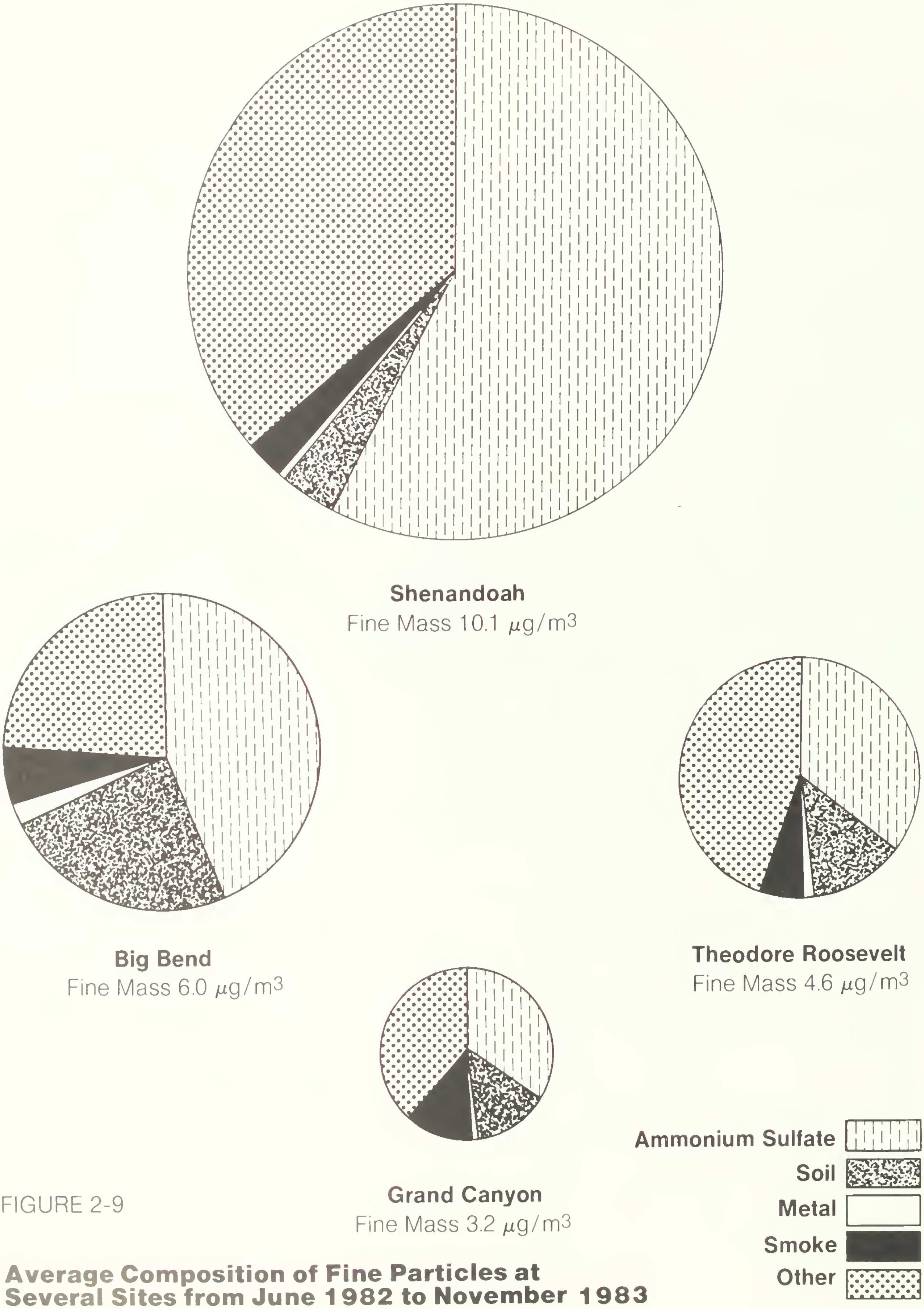


FIGURE 2-9

Average Composition of Fine Particles at Several Sites from June 1982 to November 1983

Figure 2-10 shows the average percentages of fine particulate mass made up of fine sulfate (ammonium) for June 1982 through November 1983 at the monitored NPS units throughout the western United States. Sufficient NPS data were not available to extend this to the entire country, but the sulfate component of fine particles is about 60 percent at Shenandoah National Park, which is higher than any of the monitored parks in the western United States. The sulfate content of fine particles sampled at NPS sites is the lowest at sites in the Pacific Northwest and northern Rocky Mountains. Smoke is typically the largest component of fine particles in the Pacific Northwest due to the extensive use of agricultural and prescribed forest burning.

Locations of Sulfate Aerosol Sources

The National Park Service has conducted analyses to determine the origins of sulfate aerosols found at NPS monitoring sites. The origins of sulfate aerosols have been studied through back trajectory residence time analyses, which use particulate monitoring data and meteorological data to model the path that the particles may have taken. Back trajectory analyses have been used to identify the major source regions from which "extreme" sulfur concentrations arrive at the Colorado Plateau.

The results are illustrated in Figure 2-11. Air masses carrying high sulfur concentrations apparently come most often from southern California, a heavily populated urban area. Under some meteorological conditions, air masses carry high sulfur concentrations to the Colorado Plateau from southern Arizona, an area with several copper smelters.

Similar analysis for low sulfur days shows that "clean air" is more likely to come from the areas to the north of Grand Canyon National Park. Under some meteorological conditions, air masses come to the Colorado Plateau from the north and this air is typically low in sulfur content. One important implication of these findings is that an increase in emissions of sulfur dioxide to the north of the Grand Canyon (which could be expected from major new development of energy resources and urban growth in the region) could reduce the frequency of clear air days at the Grand Canyon and other parks in the Colorado Plateau region by increasing the pollution of the air masses that typically bring clean air to the area. Increases in pollution are more noticeable when the air is initially clean. Small increments in pollution from the north would be more noticeable than the same increment from the southern California area.

Back trajectory analyses are being conducted for other parks to identify likely locations of sulfate sources. These parks include Big Bend, Glacier, and Theodore Roosevelt National Parks. Results have shown the following:

1. The primary source of high sulfate concentrations at Big Bend appears to be an urban and industrial region in north-central Mexico (Monterey) and the Gulf Coast of Texas, where there is extensive oil and gas production and refining.

2. Areas identified as sources of high sulfate concentrations at Glacier are the Front Range of the Rocky Mountains in Canada, North Dakota, and the Pacific Northwest.

3. Areas identified as sources of high sulfate concentrations at Theodore Roosevelt are the Midwest, where there is extensive urban and industrial development and local areas near the park where there is oil and gas extraction.

A state-of-the-art, long-range transport model has been developed and used by the National Park Service to estimate sulfur dioxide and sulfate concentrations within large regions of the eastern United States that include Shenandoah, Acadia, Great Smoky Mountains, and Mammoth Cave National Parks. To provide useful information for the Park Service, this model had to extend the capability of available transport models to include tracking air pollution movement in complex terrain typical of areas where NPS units are located.

The model was applied using data from selected time periods during the summer of 1978. Results have shown that a high percentage of the airborne sulfates at these four parks has resulted from emissions quite distant from the parks. Specific findings for each of the parks are as follows:

1. Approximately three-fourths of the airborne sulfate concentration at Shenandoah is a result of source emissions located more than 100 kilometers from the park.

2. Long-distance sources play a dominant role in the atmospheric sulfate and wet deposition at Acadia. In addition, the results suggest that the park appears particularly susceptible to the effects of long-distance transport during periods of persistent southwesterly flow when the Bermuda subtropical high-pressure system dominates the eastern United States.

3. Approximately nine-tenths of the sulfate concentrations at Great Smoky Mountains is attributable to sources more than 250 kilometers from the park.

4. At Mammoth Cave 40 to 60 percent of the sulfate concentrations are attributable to sources more than 150 kilometers from the park.

These modeling analyses show that industrial areas in the Ohio River Valley and Midwest generally contribute substantially to high sulfate episodes in eastern park units.

POINTS RAISED BY NPS VISIBILITY RESEARCH

Research efforts to understand the effects of manmade pollution on visibility and to assist the National Park Service in visibility management decisions continue to raise concerns. This section provides a brief discussion of these concerns.

Role of Organic Aerosols in Visibility Impairment

NPS researchers have found evidence to suggest that organic aerosols, which are small airborne particles that undergo rapid change in the atmosphere, may

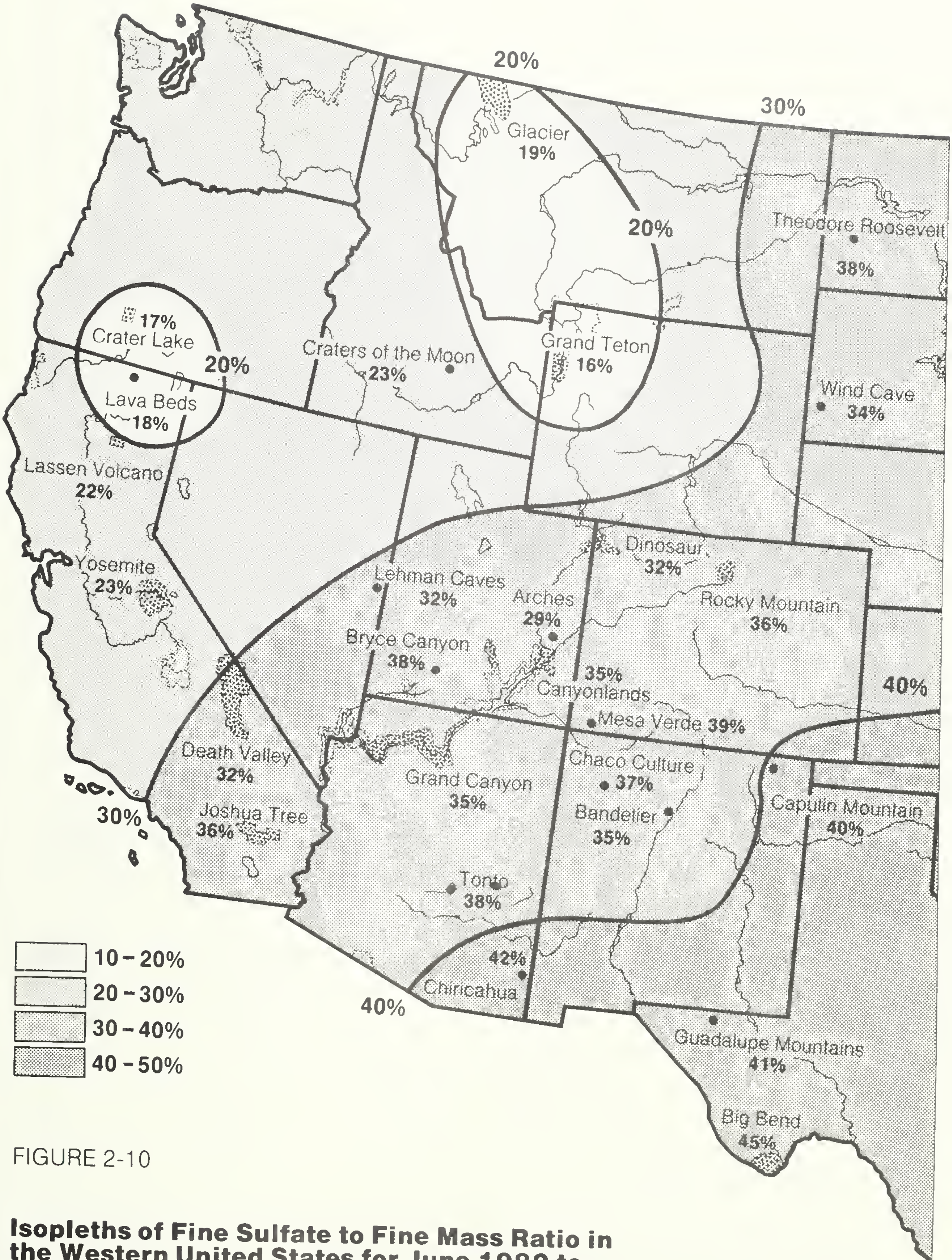


FIGURE 2-10

Isopleths of Fine Sulfate to Fine Mass Ratio in the Western United States for June 1982 to November 1983

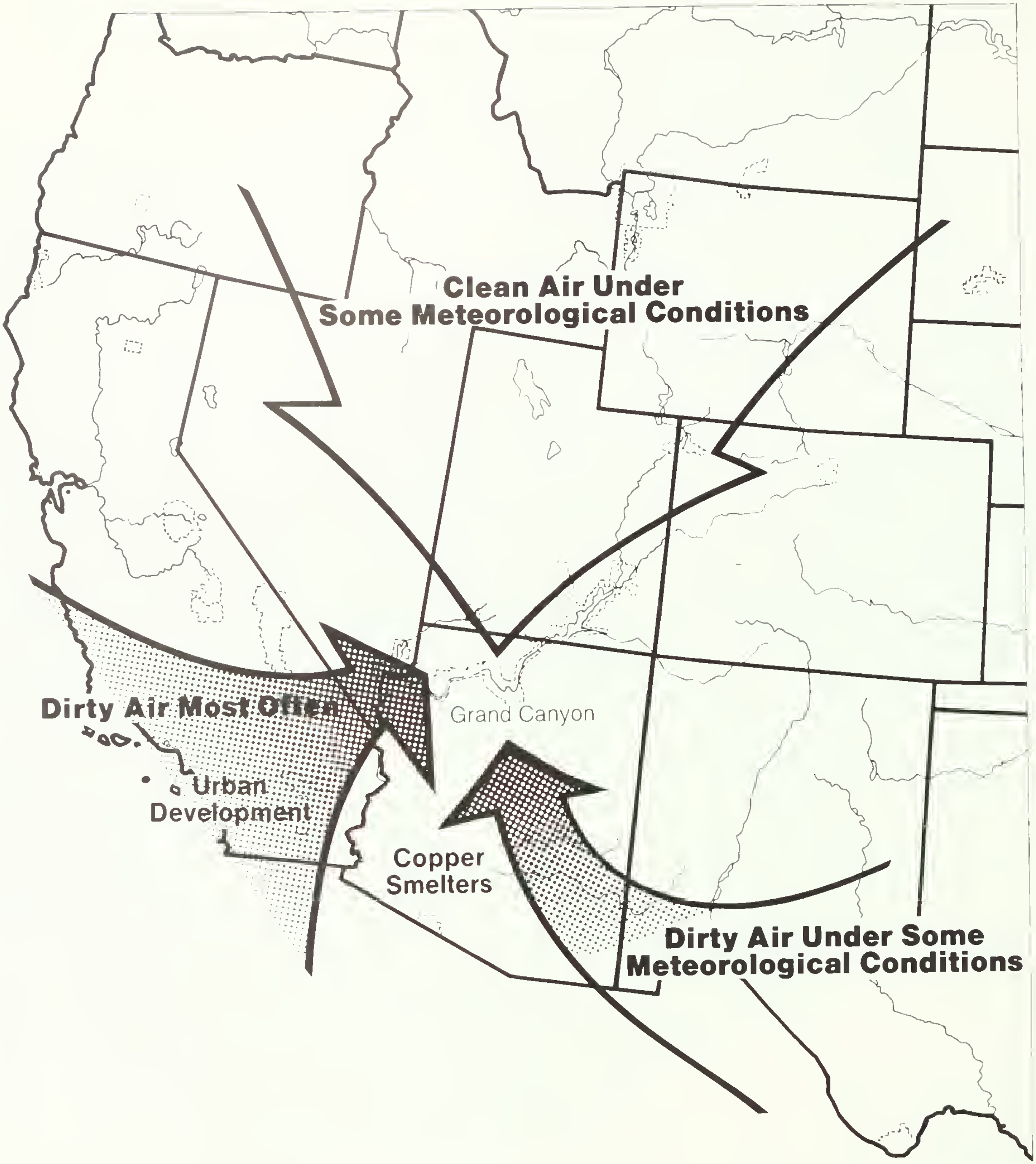


FIGURE 2-11

Origins of "Clean" and High Sulfur Content Air in the Colorado Plateau Area

be a more significant cause of visibility impairment than was previously believed.

For example, when the known effects of different particles on visibility are used to predict the visual effects of a mixture of particulates measured at an NPS monitoring site, the predicted effect on visibility is less than what is actually measured. Even when the effects of water vapor, which also is not measured by a particulate sampler, are considered, it still appears as if there is something else that affects visibility. Organic aerosols may be contributing as much as 30 percent of all visibility impairment. In fact, results from a study at Grand Canyon suggest that 30 to 40 percent of visibility impairment may be due to organic aerosols which are more volatile than ammonium sulfates. Consequently, most of the particle monitors being used in NPS units have been upgraded so that a better estimate of these aerosol concentrations, including organic carbon, can be made.

Appropriate Measurement of Visibility Conditions

The selection of visibility monitoring instrumentation is made difficult by the lack of an officially accepted definition of visibility. However, the following three distinct types of information are thought to be required in a visibility monitoring program:

1. The characteristics of a scene viewed at a distance are monitored to document the scene-specific visibility.

2. Optical properties of the atmosphere are monitored for a scene-independent measure of visibility.

3. Aerosol characteristics are determined to associate atmospheric optical properties with the responsible pollutants.

Monitoring techniques for each of these informational requirements were used before 1986, but the recent deployment of upgraded particle monitors and transmissometers has improved visibility measurement methods substantially.

Air Quality Simulation Models for Stagnation Conditions

To better estimate the impact of air pollution on NPS resources, research includes the development and application of air quality simulation models. These models can be used to predict changes in air quality that might result from proposed changes in emissions. These are valuable tools for evaluating the possible effects of a proposed activity that would increase pollutant emissions in or near an NPS unit. Air quality simulation models need to be improved for application to stagnation conditions in complex terrain, which is typical of many parks. Stagnation conditions occur when there is little mixing in the atmosphere and pollutants are retained for several days in the lower layers of the air. This can result in a build up of pollutants and a layered haze when there are emissions in an area. Models that can be applied to these kinds of conditions will improve the ability of the Park Service to predict potential visibility effects and other air quality impacts of emissions from sources affecting park units.

3.0 EFFECTS OF VISUAL AIR QUALITY ON VISITOR EXPERIENCE

The Park Service is responsible for preserving and protecting the features and natural beauty of NPS units for the enjoyment of present and future generations. In meeting this responsibility, park managers not only need to understand how air pollution is affecting park resources, but also need to know how air pollution is perceived by visitors and whether it affects visitor enjoyment. This information can help the Park Service, other federal and state agencies, and industry make resource management and pollution control decisions that will minimize undesirable impacts on the visitor experience.

The National Park Service is determining how visual air quality affects visitor perceptions and enjoyment because:

1. Viewing natural scenery and vistas is a primary activity of most park visitors.

2. Air pollution impairs views in almost all NPS units.

3. Visibility was highlighted by Congress as an important air quality related value to be protected under the Clean Air Act, and specific scenic vistas are often cited as important in park enabling legislation.

Most of the NPS research efforts concerning the effects of air pollution on visitor experience fall into one of two categories: (1) efforts to determine how the human observer perceives and judges visibility impairment, including what level is just perceptible; and (2) efforts to determine how perceived changes in visual air quality affect the visitor experience. Highlights of the findings of these two research categories are presented in Table 3-1.

HUMAN PERCEPTION OF VISUAL AIR QUALITY

In the first perception and judgment studies conducted by the National Park Service, subjects were asked to judge the visual air quality in several slides depicting vistas under different uniform haze conditions using a scale of 1 to 10, 1 being worst and 10 being best. Uniform haze is seen by a human observer as an overall reduction in air clarity. The 1 to 10 judgment is called perceived visual air quality (PVAQ), and it reflects people's perceptions and judgments concerning the visual air quality depicted in the slide. Studying the differences among the slides and their average PVAQ has helped researchers determine what factors are most important to human observers in their judgments of visual air quality.

These studies first addressed the question of whether individuals judged slides similarly to onsite views under the same air quality conditions. It was found that the PVAQ judgments are comparable, and the use of slides in studies concerning perceived visual air quality is valid and the findings are relevant to onsite viewing.

Table 3-1. Highlights of NPS Visitor Experience Research

HUMAN PERCEPTION OF VISUAL AIR QUALITY (CATEGORY 1)

Study topic:	Perceptions and Judgments of Visual Air Quality
Location and date:	Canyonlands National Park (1979); Grand Canyon and Mesa Verde National Parks (1980)
Important findings:	• Where the existing air quality is relatively pristine, even small amounts of additional air pollution are noticeable and disturbing to the viewer. Where visibility is already diminished, it takes greater amounts of pollution before a change is either noticeable or objectionable.
	• Those scenic vistas that are colored and highly textured are perceptually sensitive to small changes in air pollution. Conversely, those vistas that lack color or textural detail show little sensitivity to small increases in atmospheric pollution.
	• Plumes with a center line contrast (the contrast between the center of the plume and the background) as low as .02 can be detected by about 75% of the observers.
Study topic:	Perceptions and Judgments of Plumes
Location and date:	University of Arizona with photographs of Bryce Canyon National Park (1981)
Important finding:	• Plumes detract more from enjoyment of the view when they are dark rather than light in color and when they obscure some of the landscape features.

IMPORTANCE OF VISUAL AIR QUALITY TO VISITOR EXPERIENCE (CATEGORY 2)

Study topic:	Importance of Park Features
Location and date:	Grand Canyon and Mesa Verde National Parks (1983); Mount Rainier and Great Smoky Mountains National Parks (1984); Everglades National Park (1985)

IMPORTANCE OF VISUAL AIR QUALITY TO VISITOR EXPERIENCE (continued)

Important findings:

- Visitors rank clean, clear air among the top 4 most important features of each park studied.
- A group of features characterized by "naturalness" (meaning undisturbed by man) is the most important group of features at these parks.
- The second most important group of features is associated with the underlying theme for which the park is famous.

Study topic: Visibility and Visitor Enjoyment

Location and date: Grand Canyon and Mesa Verde National Parks (1983)

Important findings:

- Visitors' awareness of haze is closely correlated with standard visual range.
- Impaired visibility detracts from visitors' enjoyment and satisfaction with their visit.

Study topic: Willingness to Pay for Visual Air Quality

Location and date: Grand Canyon National Park (1980, 1983) and Mesa Verde National Park (1980)

Important findings:

- Visitors say they are willing to spend additional time traveling or pay additional entrance fees to obtain better visual air quality during their park visit.
- Visitors appear to be more disturbed by deterioration in visibility when the air is relatively clean.

Study topic: Willingness to Pay for Preservation of Visibility in Southwestern Parks

Location and date: Los Angeles, Denver, Chicago, and Albuquerque (1980)

Important finding:

- Households are willing to pay to preserve visual air quality at the Grand Canyon and other southwestern parks, whether or not they have visited or intend to visit the parks. This is called preservation value.

Another important finding is that the PVAQ judgments made by different people are reasonably consistent with each other, and do not appear to vary in any systematic way with the demographic characteristics of the individuals, such as age, sex, or education. This suggests that the average PVAQ judgment for a given slide can be interpreted as representative of the judgment of a typical viewer.

The average PVAQ judgments for all the slides that showed various levels of uniform haze have been studied to determine their relationship to objective measures of visibility conditions, such as contrast, visual range, or light extinction. There appears to be a strong relationship between the PVAQ judgment and the contrast transmittance of the vista. Contrast transmittance is a measure of the ease with which the atmosphere transmits the image of the vista to the viewer. In cases when the foreground of the vistas is not affected, but the change in pollution affects the view of a dominant distant feature, then the change in the contrast of the dominant distant feature alone is adequate to explain the change in the PVAQ judgment.

The analysis of the PVAQ judgments has revealed that increases in air pollution are more noticeable and objectionable to the human observer when the air is relatively clean. This is illustrated in Figure 3-1, which shows the relationship between the PVAQ judgment and ambient particulate levels. The curved line indicates that a one-unit increase in particulates will result in a much larger decrease in the PVAQ at the lower particulate levels than at the higher particulate levels.

These studies were also able to test whether the perceived visual air quality is more sensitive to changes in air pollution at some vistas than at others. The results indicate that people find increases in air pollution more objectionable in vistas with features that are more highly colored and textured.

NPS researchers have developed methods for determining when a layered haze or plume is just perceptible. A layered haze or plume results when pollutants are not uniformly mixed in the atmosphere making it possible to see the "edge" of the polluted air mass. Two plumes with center line contrast of -.11 and -.13 are shown in Figure 3-2 to illustrate what the contrast measures mean. Center line contrast is the contrast between the center of the plume and the background. It is negative if the plume is darker than the background and positive if it is lighter.

Figure 3-3 shows the percentage of the observers who could detect a brown plume (caused by nitrogen dioxide) at various levels of the center line contrast of the plume. At a contrast of -.02 approximately 75 percent of the observers were able to detect the plume, and at -.04 nearly 100 percent were able to detect the plume. This study also found that viewers perceive a dark-colored plume to be more objectionable than a white plume. Plumes that obscure some of the features in the vista were also considered worse than plumes that were seen only against the sky.

Additional work is being conducted to determine the amount of layered haze that is just perceptible to human observers and how the perceptibility of layered haze and plumes is affected by characteristics such as size, shape, and sharpness of the edge, and color of the polluted air mass.

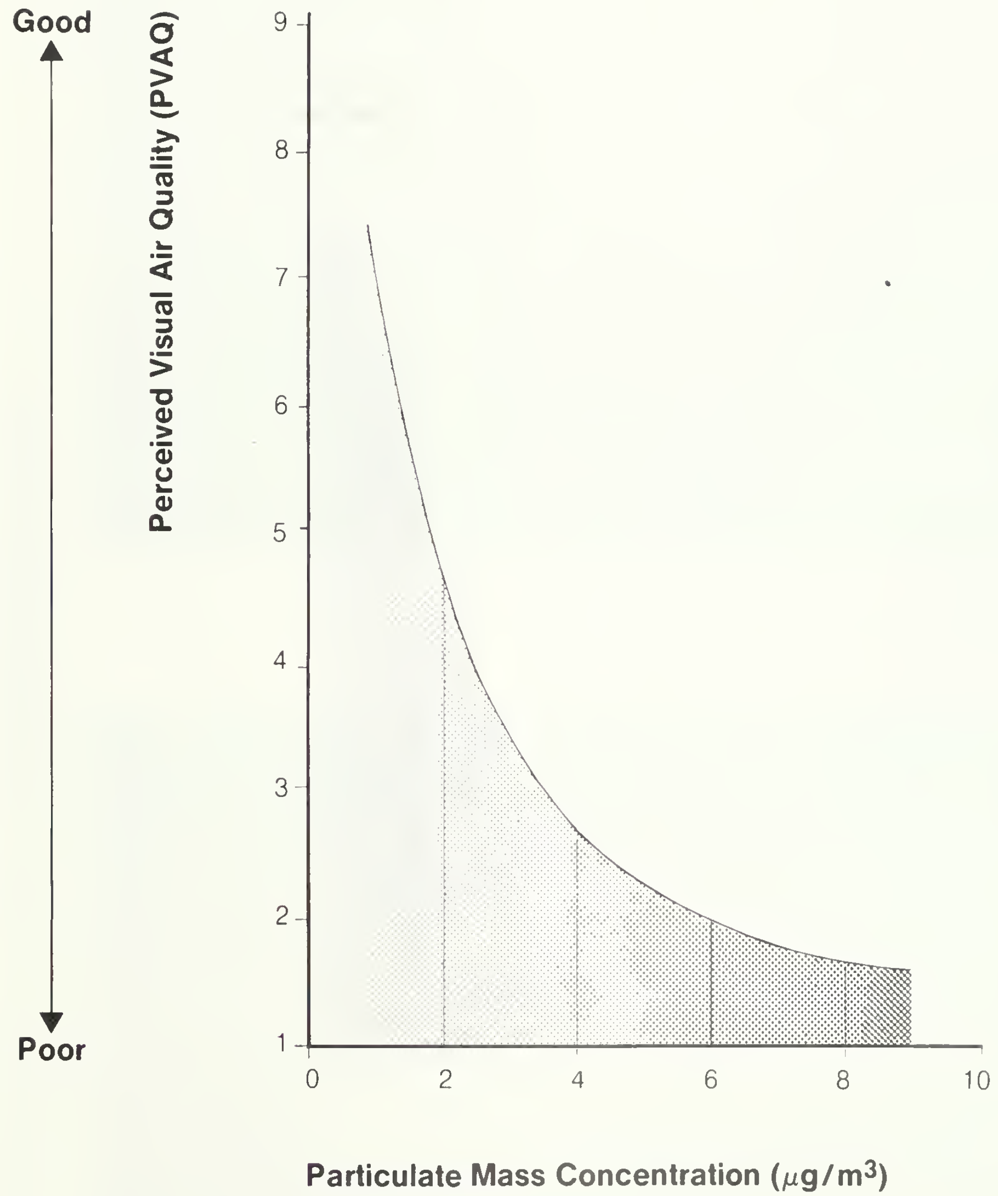


FIGURE 3-1

Relationship Between Perceived Visual Air Quality and the Amount of Particulates in the Air

Plume/Sky Contrast = -.11

Plume/Sky Contrast = -.13

FIGURE 3-2

EXAMPLES OF CONTRAST MEASURES OF BROWN PLUMES AT NAVAJO NATIONAL MONUMENT

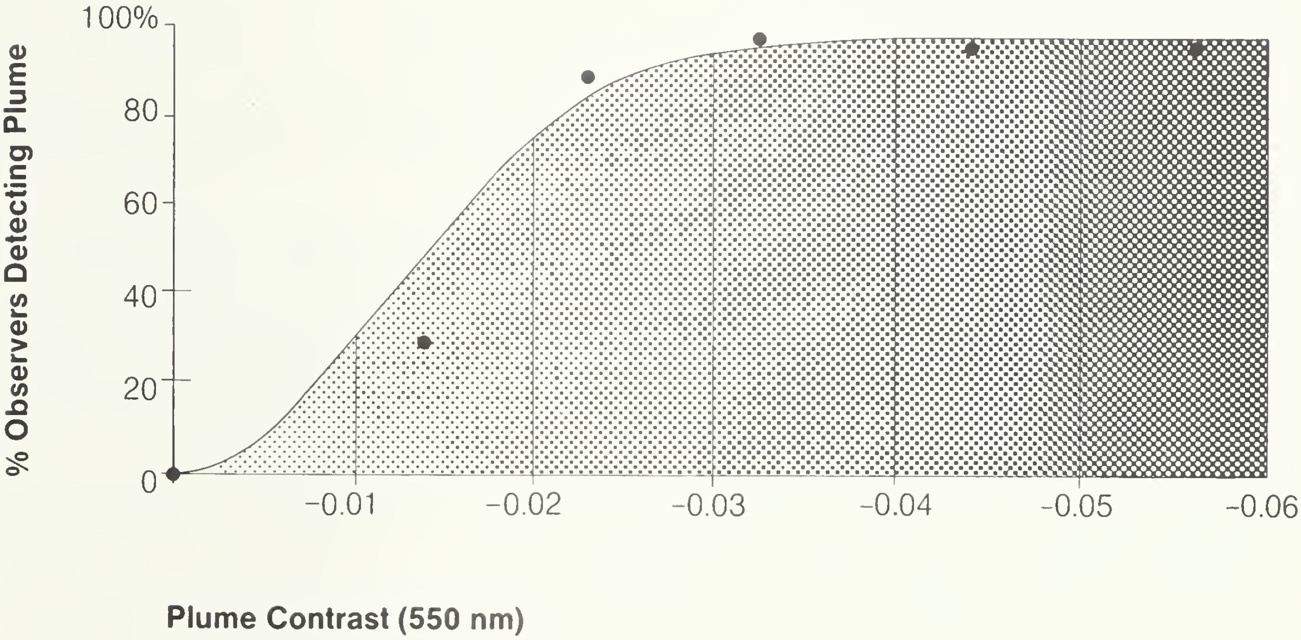


FIGURE 3-3

Percentage of Observers Who Could Detect a Brown (Nitrogen Dioxide) Plume as a Function of Plume Contrast

The first few NPS perception and judgment studies set the foundation for subsequent research on the effects of visual air quality on visitor experience. These studies suggested that visitors do have preferences concerning visibility conditions and that a variety of circumstances, such as vista content and initial air quality, influence changes in perceived visual air quality. The next question addressed was how perceived visual air quality affects the individual's visit to the park.

IMPORTANCE OF VISUAL AIR QUALITY TO VISITOR EXPERIENCE

One of the reasons people visit parks is to see and enjoy the scenery. Therefore, it is useful to consider visual air quality conditions from the point of view of the human observer. The National Park Service has conducted studies that examine the following:

- The importance of clean air as a park feature.
- Visitor awareness of visibility conditions.
- The relationship between visibility conditions and satisfaction/ enjoyment of the park visit.
- Willingness of the visitor to expend time and/or money to obtain improved visibility conditions.

Findings obtained from these research efforts suggest that visitors are aware of visibility conditions and that clean, clear air is integral to the enjoyment of visiting the parks. The most important conclusions based on these findings to date are summarized.

Finding: An Environment Undisturbed By Man, Including Clean, Clear Air, Is Very Important To Park Visitors

In NPS studies during the summers of 1983, 1984, and 1985, visitors at Grand Canyon, Mesa Verde, Mount Rainier, Great Smoky Mountains, and Everglades National Parks were given a list of park features and asked how important each one was to their recreational experience. Some of the listed features were the same at all the parks and some were specific to each park. For example, "clean, clear air" and "interpretive signs" were listed for all the parks while "viewing canyon rims" was listed for Grand Canyon, "ruins on mesa tops" was listed for Mesa Verde, "alpine glaciers" was listed for Mount Rainier, "views of chimney tops" (natural landscape features in the area) was listed for Great Smoky Mountains, and "variety and presence of reptiles" was listed for Everglades. A total of 24 features were included on the list for Grand Canyon and Mesa Verde, 23 at Great Smoky Mountains, 8 at Mount Rainier, and 31 at Everglades.

At each of the five parks, "clean, clear air" was ranked among the top 4 features. For example, 82 percent of the 638 respondents at Grand Canyon rated "clean, clear air" as "very important" or "extremely important" to their recreational experience. Only "cleanliness of the park" and "deep gorges" were rated higher at Grand Canyon. Several of the scenery-related

features were also "very important" especially at Grand Canyon and Mount Rainier. Flora- and fauna-related features were "very important" at all five parks.

Cluster analysis was used to determine if clusters, or groups of park features, could be identified based on visitors' responses. This analysis was performed not only to reduce the large number of variables involved, but also to determine which park features belong to certain "domains" of features in the visitors' minds. For example, it might be expected that features related to park management might cluster into one group, while features related to the park's natural resources would cluster into another group. Results showed five clusters of features at Grand Canyon and Mesa Verde, three at Mount Rainier, seven at Great Smoky Mountains, and nine at Everglades.

The analysis yielded a number of interesting trends. First, a cluster of features was identified at all five parks that could be associated with the natural environment undisturbed by humans. This set of features is referred to as the naturalness cluster. "Clean, clear air" and "cleanliness of park" were in the naturalness cluster at every park. "Rivers and streams" and "clean, pure water in lakes" were in the naturalness cluster in the parks where these features were listed. Features related to vegetation and wildlife were also in the naturalness cluster at two of the five parks.

Figure 3-4 shows the clusters of features and their relative importance at each park. The ratings are the averages of those given by all respondents. The most significant finding reflected in Figure 3-4 is that the naturalness cluster was rated the most important at each park. The cluster analysis suggests that the second most important set of features is associated with the underlying theme for which the park is famous. For example, while naturalness was the most important cluster of features at both Grand Canyon and Mesa Verde, a view-related cluster at Grand Canyon and an information-related cluster (which emphasized park history) at Mesa Verde ranked as the second most important cluster of features at those parks, respectively. At Everglades, fauna-related features were grouped into a separate cluster that was almost as important as the naturalness cluster. The viewing cluster, including views of distant horizons and sunrises/sunsets, was less important.

It appears that people visit these parks first to experience a natural setting and second to enjoy specific unique features associated with various parks. The survey results show it is very important to visitors that parks be natural and free of pollution--undisturbed by man. These findings suggest that if these resources are allowed to deteriorate, visitor enjoyment of the parks would decline.

Finding: Visitors Are Aware Of Visibility Conditions

The visibility and visitor experience study conducted at Grand Canyon and Mesa Verde National Parks in 1983 found that visitors are able to perceive varying degrees of visibility impairment. Visitors interviewed as they left viewing points in the parks were asked if they had noticed haze and if so whether they thought it was slightly, moderately, very, or extremely hazy. Their responses were compared to standard visual range estimates based on teleradiometer readings taken three times daily. The comparison revealed that when standard

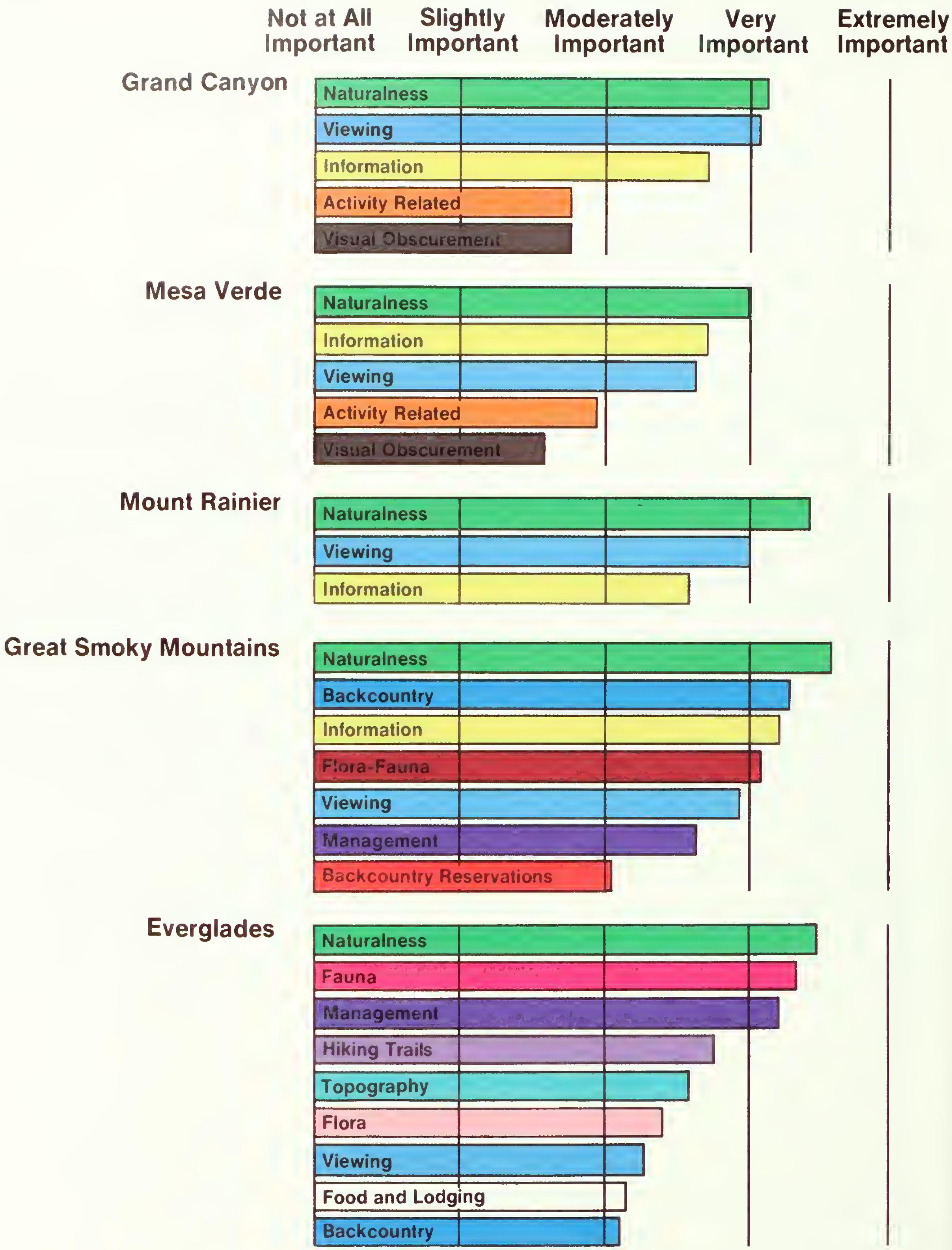


FIGURE 3-4 **Average Visitor-Rated Importance of Park Features**

visual range was lower, visitors were more aware of haze and were more likely to say it was "very" to "extremely" hazy.

The varying demographic backgrounds of those interviewed (size of home community, income, age, and sex) did not correlate with their perceptions of haze. Visibility at Grand Canyon is typically better than in many other places in the country, yet the survey results indicate that visitors are aware of visibility conditions and are able to detect the presence of haze.

Finding: Visual Air Quality Influences Visitor Enjoyment And Satisfaction

Results of the 1983 NPS visibility and visitor experience research at Grand Canyon and Mesa Verde National Parks show that those visitors who said they thought the view was "very" to "extremely" hazy also said they enjoyed the view less, enjoyed the park less, and were less satisfied with visibility conditions than those who said they were not aware of haze or were aware of only slight to moderate haze. This means that not only do most visitors notice haze, but when they consider the view to be relatively hazy it detracts from their enjoyment of the park.

Visitors at Grand Canyon and Mesa Verde National Parks were asked to rate the importance of 33 recreational experiences at the park that they might find satisfying, such as learning about the park's history, knowing that the park resources and values are being protected, and doing something with one's family. Those experiences pertaining to the existence of the park, including the satisfaction of knowing that the park resources are being protected, were rated as the most important by visitors at both parks. When combined with the findings discussed earlier, these findings indicate that:

- Visitors derive the most satisfaction from knowing that the park is there and that the park resources are being protected.

- Visitors feel that the natural environment of the park (which includes clean, clear air) is the most important of all the park resources.

Finding: Visual Air Quality Conditions Affect The Amount Of Time And Money Visitors Are Willing To Spend At NPS Units

Three NPS studies have been conducted to evaluate whether visitors would be willing to spend more time traveling to vistas or pay higher entrance fees in order to obtain better visual air quality during their park visit. Those questioned generally responded that they would be willing to spend more time and money if visibility conditions were better and less if visibility conditions were worse. These results provide evidence that changes in visual air quality can be expected to affect visitors' enjoyment and satisfaction with park visits.

These studies are based on the presumption that people will allocate the time and money available to them in such a way as to maximize their enjoyment. Therefore, a change in the amount of time or money they are willing to spend is a reflection of the change in enjoyment.

In the 1983 NPS study at Grand Canyon, 244 visitors were asked to rank possible alternative combinations of travel time to vistas and visibility conditions (illustrated with photographs). These rankings revealed that the average change in the amount of time the visitor was willing to spend traveling to a vista for every unit change in visibility (.01 km^{-1} extinction coefficient) was between 15 minutes and 4 hours.

The differences in the amount of time visitors were willing to spend to obtain better visibility were related to the vista and the hypothesized initial visibility level. Vistas with more texture and color, dominant distant features, and better initial visibility levels were the most sensitive. For example, the average increase in the amount of time the visitors were willing to spend traveling to the San Francisco Peaks vista in exchange for a unit increase in visibility (.01 km^{-1} drop in extinction coefficient) was between 1.5 and 4 hours when the initial visual range was over 200 kilometers and was between 1 and 1.5 hours when the initial visual range was less than 200 kilometers. The average increase in travel time for the Desert View vista, where distant features are not dominant and the photographs were taken at a time of day when the vista was heavily shadowed and therefore showed little color or textural detail, was between 15 minutes and 1 hour.

The findings of this study showing that visitors are more disturbed by deterioration in visibility when the air is relatively clean and when the vista is highly colored and textured are consistent with those of the human judgment studies discussed earlier in this chapter. This is also in agreement with the findings of the visitor experience studies which suggest that an environment undisturbed by man is one of the features most valued by visitors in a national park. The "willingness to pay" studies should not be interpreted as reflecting the total value of a visit to a park. Rather, willingness to pay for a change in visibility is one way to quantify the associated change in enjoyment, using dollars as an index of value.

A 1980 NPS study at Grand Canyon and Mesa Verde National Parks examined the effect of visibility conditions on the amount visitors are willing to pay in park entrance fees. Average responses were about one dollar per visitor-party to have 160 kilometers visual range rather than 110 kilometers visual range, about two dollars to have 210 kilometers rather than 110 kilometers, and about three dollars to have 350 kilometers rather than 110 kilometers. Annual visitation at the Grand Canyon in 1980 was 2,305,000 people, with an average of about 3 people to each visitor-party. To prevent a visible plume over the Grand Canyon the average payment cited was about two dollars per visitor-party. Similar studies conducted by others outside the National Park Service have typically received comparable or higher willingness to pay responses.

A study concerning willingness to pay for preservation of visibility at southwestern parks was funded by the U.S. Environmental Protection Agency and conducted in cooperation with the National Park Service in 1980. The focus of this study was the development of methods for quantifying preservation value, which is the value to the individual of knowing that the parks are being preserved whether or not the individual intends to use the park. It was found that users and nonusers throughout the country are willing to pay to preserve and protect visibility at Grand Canyon National Park and throughout the Southwest. The responses from those who did not plan to visit the area were

not significantly different from those who were planning to or had previously visited the area.

The average household willingness to pay was about five dollars per month to prevent deterioration in visibility at Grand Canyon and an additional four dollars per month to prevent visibility deterioration throughout the remainder of the region, which includes several other NPS units. This suggests that preservation values for Grand Canyon may be considerably higher than for other parks. The finding that people who never intend to visit the parks are willing to pay to protect park resources supports the conclusion that simply knowing that the parks are there and being protected is important and valuable.

POINTS RAISED BY NPS VISITOR EXPERIENCE RESEARCH

The NPS visitor experience research has raised concerns on how best to protect and preserve NPS resources for the enjoyment of current and future visitors. This section summarizes two of these concerns.

Developing Adverse Impact Determination Guidelines

The National Park Service has defined several criteria for determining whether increases in air pollution will have an adverse effect on a park's air quality related values. (See Chapter 6 for more discussion of the adverse impact determination.) One of these criteria is whether the effects of the change in air quality impair the quality of the visitor experience. Visitor experience research findings have raised questions that could affect the interpretation of this criterion. For example, given the importance that visitors apparently place on the naturalness of the parks, what level of visibility impairment should be considered adverse?

Determining Just Perceptible Changes in Visual Air Quality

Progress has been made in determining when a plume will become just visible to the human observer. Work that has been done with plumes and layered hazes suggests that the size, shape, and color may be important factors influencing when the plume or layered haze will be just perceptible, but how these differences affect perceptions has not been quantified. Uniform haze raises a slightly different question in that the issue is usually not how much haze is just noticeable relative to a pristine atmosphere, but how much of a change is just noticeable when some haze already exists. Initial results suggest that the human observer finds the same increase in haze more undesirable in a clearer atmosphere than in a hazier atmosphere. Additional work is needed to quantify the minimum change in uniform haze that is just perceptible and to determine the factors that influence the perceptibility of changes in uniform haze.

4.0 CRITERIA POLLUTANTS IN NPS UNITS

Criteria air pollutants are those for which the U.S. Environmental Protection Agency has established National Ambient Air Quality Standards as directed by the Clean Air Act. These standards are established for those pollutants that are emitted in the greatest quantities throughout the country and are a danger to public health and welfare. Criteria air pollutants include ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter, and lead.

An extensive national network of monitoring for criteria pollutants is currently operated by state and local (city/county) air pollution control agencies. The focus of this monitoring network is urban areas and other areas where pollution levels are relatively high due to the impact of nearby emission sources such as coal-fired power plants, petrochemical plants, and pulp and paper mills. Little monitoring has been done in areas such as those in the National Park System that are thought to be relatively free of pollution. Research by the National Park Service and others, however, has found effects from some of these air pollutants on biological and visibility resources in some NPS areas. More information is needed on ambient pollution levels in the parks.

The Park Service has responded by establishing a criteria pollutant monitoring program for the pollutants linked to effects on NPS resources. Results of this monitoring program indicate that elevated levels of some criteria pollutants occur in several NPS units.

NPS CRITERIA POLLUTANT MONITORING PROGRAM

The NPS criteria pollutant monitoring network has been designed to meet certain resource management objectives and to ensure collection of data needed for the Park Service to comply with regulatory requirements. One of the primary objectives is to establish baseline (or current) air quality conditions in NPS units so that trends can be analyzed and assessments made of whether an area is exceeding National Ambient Air Quality Standards or prevention of significant deterioration increments for clean air areas. A monitoring station may also be established if there is documented biological injury due to air pollution in the park unit. Information on ambient air pollution levels is an important supplement to research on effects of air pollutants on NPS resources and can help confirm suspected causes of observed effects. Information on air quality levels in NPS units is also used to evaluate the performance of atmospheric models. The models can help determine how pollutants are transported into an area and predict impacts of proposed new air pollution sources.

Other monitoring objectives relate to collecting data needed to support the National Park Service's required involvement in the development of state air quality control plans and in the evaluation of permit applications for new or expanding air pollution sources wishing to locate near a class I area. The Clean Air Act gives federal land managers and superintendents an affirmative responsibility to protect air quality related values in class I areas and to assess whether new sources will have an adverse impact on park resources and values. Therefore, the presence or expectation of considerable permitting activity near an NPS unit makes it a good candidate for monitoring.

From 1981 through 1984 the NPS criteria air pollutant monitoring program was developed. As of the summer of 1985, one or more criteria pollutants were being monitored in 19 NPS units. The monitoring network has been extended to include more NPS units. During 1986 and 1987, at the request of Congress, criteria pollutant monitoring stations were established at 17 additional units including Arches, Badlands, Carlsbad Caverns, Haleakala, Hawaii Volcanoes, Isle Royale, Lassen Volcanic, Petrified Forest, Redwood, Virgin Islands, Voyageurs, and Yellowstone National Parks; Bandelier, Great Sand Dunes, and Pinnacles National Monuments; Denali National Park and Preserve; and Point Reyes National Seashore.

Ozone, which is apparently responsible for widespread foliar injury and possible ecological effects in many NPS units, is measured at all monitoring sites. Sulfur dioxide is also monitored at most sites. Figure 4-1 shows the location of NPS ozone and sulfur dioxide monitoring sites. State or local agencies monitor nitrogen dioxide at Channel Islands National Park and Congaree Swamp National Monument. In addition, state agencies have established total suspended particulate matter monitoring stations (as distinguised from fine particle monitoring conducted by the NPS visibility program discussed in Chapter 2) at almost a dozen NPS units.

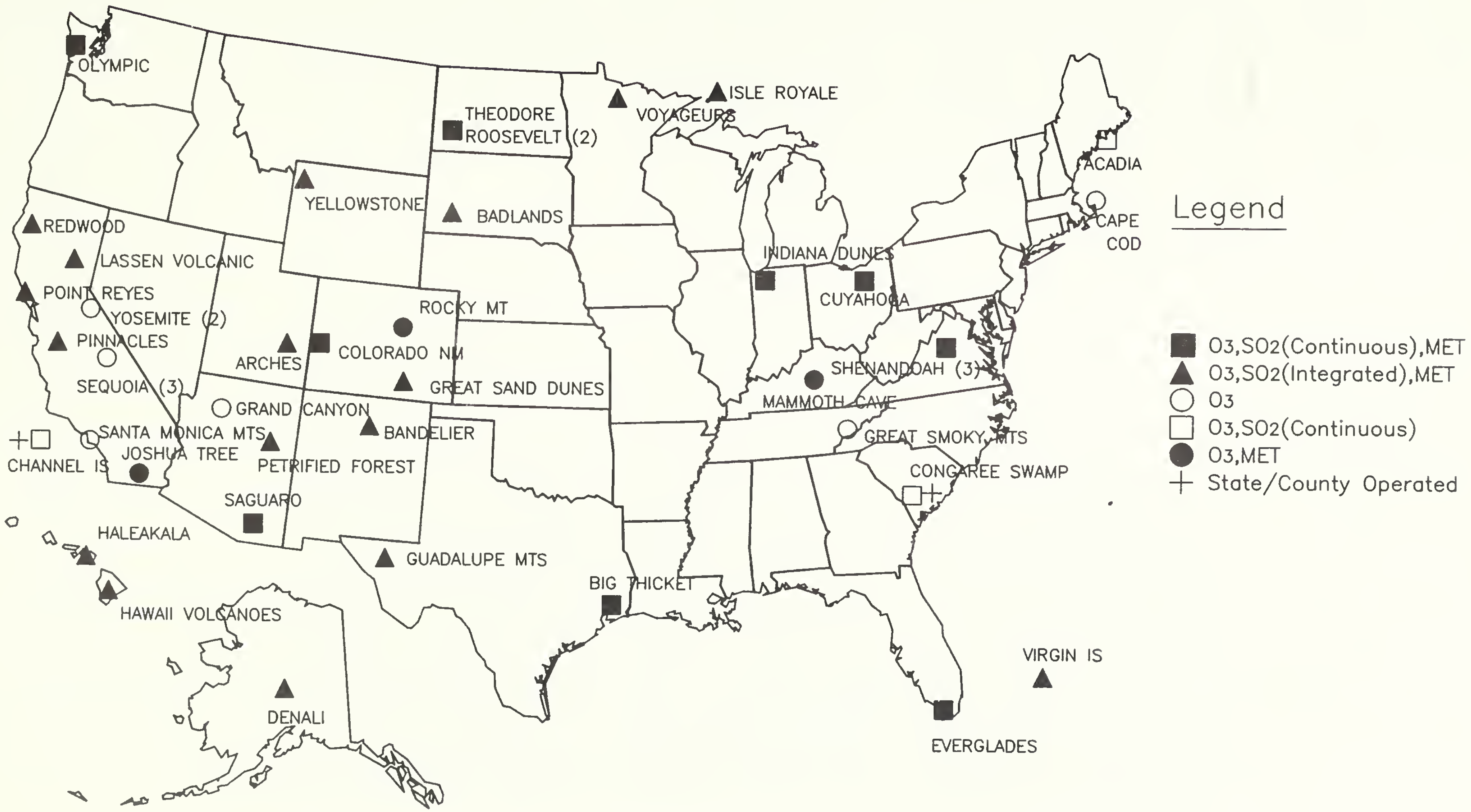
Monitoring methods and quality assurance procedures used in the collection of criteria pollutant data for NPS units are those recommended by the U.S. Environmental Protection Agency and are consistent with applicable regulations (40 CFR Part 58). This allows for the direct comparison of NPS-collected data with that collected by state and local air pollution control agencies and by the U.S. Environmental Protection Agency, and acceptance of the data by state and EPA analysts. In addition, a computerized data base is being established that will allow for easy access and analysis of the data.

CRITERIA AIR POLLUTANT LEVELS IN NPS UNITS

There are two types of National Ambient Air Quality Standards--primary and secondary. The primary standards are set to protect human health. For some pollutants, public welfare might be endangered at pollution levels below those at which no human health effects are known to occur. For example, injury to plants and damage to materials may occur at ambient levels of sulfur dioxide that are not expected to have any effect on human health. In these cases, secondary standards are set to protect public welfare. The standards are also defined in terms of averaging times, such as annual or hourly, depending on the frequency and duration of exposure that is associated with health and welfare effects. For some pollutants, there are both short-term and long-term standards.

The analysis of the monitoring data that are currently available shows that NPS units are not immune from elevated levels of ozone and sulfur dioxide and that elevated pollution levels are not limited to NPS units adjacent to large urban areas. Although levels of sulfur dioxide are well within the National Ambient Air Quality Standards, ozone levels have exceeded or have equalled the National Ambient Air Quality Standards at several NPS units. Data from the nitrogen dioxide and total suspended particulate matter monitoring at NPS units are not yet available. Similarly, data from monitoring sites established during 1986 and 1987 is still being validated and analyzed.

FIGURE 4-1
NPS GASEOUS POLLUTANT MONITORING NETWORK



The primary National Ambient Air Quality Standard for ozone is a 1-hour average of 120 parts per billion (ppb) not to be exceeded more than once a year. The secondary standard is currently the same as the primary standard. Results of research by the Park Service and others, however, indicate that foliar injury to some native and cultivated plant species occurs at ozone concentrations as low as an 8-hour average of 60 ppb. The scientific basis for the current ozone standard is currently being reviewed by the U.S. Environmental Protection Agency, and possible changes are being considered.

Table 4-1 shows the NPS units for which ozone data are available for 1982 through 1986. The maximum hourly average and the number of times the National Ambient Air Quality Standard was exceeded is listed for each year. The level of the National Ambient Air Quality Standard for ozone has been exceeded at three NPS units located near large urban areas: Channel Islands National Park, Indiana Dunes National Lakeshore, and Santa Monica Mountains National Recreation Area; and at three NPS units in more remote locations: Acadia National Park, Joshua Tree National Monument, and Sequoia National Park. Additionally, recorded ozone levels have equalled the level of the standard at Shenandoah National Park and Congaree Swamp National Monument, and have reached over 90 percent of the level of the standard at Great Smoky Mountains National Park and Saguaro National Monument. There are not sufficient data to show a significant trend over time, either increasing or decreasing, for any of these parks.

The primary National Ambient Air Quality Standard for sulfur dioxide is set for two averaging times. The annual standard is 30 ppb, which is not to be exceeded, and the 24-hour standard is 140 ppb, which is not to be exceeded more than once a year. There is also a separate secondary standard for a 3-hour averaging period of 500 ppb. This secondary standard takes into account evidence concerning foliar injury to sensitive tree species observed as a result of single exposures to sulfur dioxide concentrations of this level. There is also evidence that long-term exposures to sulfur dioxide below the primary annual standard result in the disappearance of sensitive lichen species. This is commonly observed at annual sulfur dioxide concentrations of about 15 ppb and has been observed at concentrations as low as 6 ppb.

Table 4-2 shows available sulfur dioxide concentration data for NPS units for 1980 through 1987. None of the National Ambient Air Quality Standards were exceeded at these parks during these years, but levels as high as 48 percent of the secondary standard have been recorded. The highest sulfur dioxide concentrations measured at the five parks in 1984 were at Olympic National Park. Sulfur dioxide concentrations measured at Indiana Dunes National Lakeshore have been about 20 to 40 percent of the standard each year. The monitoring results indicate a significant decrease in sulfur dioxide concentrations at Theodore Roosevelt National Park from 1982 to 1984. This reduction in observed levels is associated with control actions implemented by the North Dakota Department of Health in cooperation with the National Park Service.

Table 4-1. Ozone Monitoring Levels at NPS Units 1982-1986

	*Acadia	*Channel Islands	Colorado	Congaree Swamp	Cuyahoga Valley	Great Smoky Mtns.	*Indiana Dunes	*Joshua Tree	Mammoth Cave
1982 Highest Hourly Ozone				60					
Number of NAAQS Exceedance				0					
1983 Highest Hourly Ozone	138			120					
Number of NAAQS Exceedance	3			0					
1984 Highest Hourly Ozone	140	100		---		119	155		
Number of NAAQS Exceedance	1	0				0	4		
1985 Highest Hourly Ozone	120	200	74	76	93	---	115	140	105
Number of NAAQS Exceedance	0	1	0	0	0		0	2	0
1986 Highest Hourly Ozone	109		85	---	115		125	160	109
Number of NAAQS Exceedance	0		0		0		1	3	0

The primary and secondary National Ambient Air Quality Standard (NAAQS) for ozone is an hourly average concentration 120 parts per billion (ppb), not to be exceeded more than once a year on average.

* NPS units exceeding NAAQS for ozone

	Olympic	Saguaro	*Santa Monica Mtns.	*Sequoia	Shenandoah	Theodore Roosevelt
1982 Highest Hourly Ozone	60	100		150		
Number of NAAQS Exceedance	0	0		10		
1983 Highest Hourly Ozone	50	111		120	120	80
Number of NAAQS Exceedance	0	0		0	0	0
1984 Highest Hourly Ozone	60	108	220	130	115	70
Number of NAAQS Exceedance	0	0	15	1	0	0
1985 Highest Hourly Ozone	50	105	280	140	110	60
Number of NAAQS Exceedance	0	0	46	4	0	0
1986 Highest Hourly Ozone		85	170	140	110	62
Number of NAAQS Exceedance		0	4	1	0	0

The primary and secondary National Ambient Air Quality Standard (NAAQS) for ozone is an hourly average concentration 120 parts per billion (ppb), not to be exceeded more than once a year on average.

* NPS units exceeding NAAQS for ozone

Table 4-2. Sulfur Dioxide Concentrations at NPS Units 1980-1987

	Cuyahoga Valley			Theodore Roosevelt (North Unit)			Theodore Roosevelt (South Unit)			Indiana Dunes			Olymic			Shenandoah		
	3hr	24hr	Annual	3hr	24hr	Annual	3hr	24hr	Annual	3hr	24hr	Annual	3hr	24hr	Annual	3hr	24hr	Annual
1980 Maximum Concentrations (ppb)				34	12	1.5	11	43	1.1									
1981 Maximum Concentrations (ppb)				58	14	1.5	20	4	1.1	132	62	--						
1982 Maximum Concentrations (ppb)				152	62	3.4	12	6	1.1	149	42	--	143	42	2			
1983 Maximum Concentrations (ppb)				72	15	1.9	12	5	1.1	158	61	6.9	90	23	3	52	25	4.5
1984 Maximum Concentrations (ppb)				32	16	1.5	10	3	1.1	110	39	--	240	60	--	77	36	5.9
1985 Maximum Concentrations (ppb)	75	33	--	33	14	1.5	6	3	1.1	139	54	--	90	30	0	67	40	6.4
1986 Maximum Concentrations (ppb)	121	47	--	45	11	1.5	12	3	--	76	31	6.5	220	40	1	65	35	--
1987 Maximum Concentrations (ppb)																51	18	

The National Ambient Air Quality Standard for sulfur dioxide are:

3 hour	(secondary standard)	500 parts per billion (ppb)
24 hour	(primary standard)	140 parts per billion
Annual	(primary standard)	80 parts per billion

-- Insufficient data

5.0 AIR POLLUTION EFFECTS ON BIOLOGICAL RESOURCES

Ozone affects biological resources in many NPS units. In a few areas, such as Sequoia and Acadia National Parks, the effects are dramatic. In many other areas more subtle effects have been found on vegetative types known to be sensitive to various air pollutants. For instance, at Indiana Dunes National Lakeshore there has been a large decrease in the kinds of lichens found there, with those known to be sensitive to sulfur dioxide now vanished or surviving only in greatly diminished numbers.

The NPS air quality biological effects research program represents one of the most extensive efforts in the United States to study air pollution effects on native plant species. The program has focused on plants because they are usually more sensitive to air pollution than animals and show the first biologically detectable effects of air pollutants. The biological effects research program is designed to:

1. Determine the sensitivity of native plants to different air pollutants.

2. Identify air pollution impacts on sensitive plants.

3. Establish baseline conditions of plants and monitor trends in NPS ecosystems.

Information from this research program helps to identify current or potential problems that might be mitigated or eliminated through implementing alternative resource management strategies and cooperating with local authorities and industry. The information also helps in the review of permit applications and environmental impact assessments concerning proposed new sources of air pollution that might affect the biological resources of parks.

This chapter describes the effects of air pollution on plants, explains the studies which have been conducted to determine the extent and severity of air pollution effects on NPS biological resources, and summarizes the findings of the NPS biological effects research program to date.

EFFECTS OF AIR POLLUTION ON PLANTS

The National Park Service is most interested in the effects of pollution on native vegetation. Although extensive literature exists on the effects of air pollution on agricultural crops and commercial forests, this information is of limited use to the Park Service because most of it is not specifically applicable to native plant species. However, many of the research methods and general findings developed in previous applications can be applied to the study of native plants. For example, studies indicate that there is considerable injury to agricultural crops in the United States from ozone and sulfur dioxide, suggesting that these two pollutants may also be affecting native species in national parks. The Park Service is conducting studies and reviewing information that is available in the literature to determine possible effects of air pollution on natural vegetation.

The effects of an air pollutant on biological resources are influenced by various factors, including the following:

- Toxicity of the pollutant.
- Exposure of the organism to the pollutant.
- Sensitivity of the organism, which varies with inherited factors, nutritional status, season, and age.
- Potential for synergisms with other pollutants.

Assessing the significance of air pollution injury requires knowing:

- Affected organism's role in the ecosystem.
- Persistence of the pollutants in the environment.
- Potential reversibility of the effect on the organism and ecosystem.
- Geographical scale of the injury.
- Severity of the injury.

Effects may be the result of acute or chronic exposures or both. The former are short-term exposures to high pollution levels, whereas the latter are long-term exposures to lower pollution levels.

Three categories of effects have been studied in the NPS biological effects research program:

1. Foliar injury which may appear as spots on, or discoloration of, leaves.
2. Ecological effects which include stunted growth, altered reproduction, and death of individual plants or entire species.
3. Elevated levels of potentially toxic trace elements, such as arsenic and lead, in plant tissue which have resulted from particulate deposition. These elevated levels may or may not be accompanied by detectable injury to the organism.

Foliar Injury

Leaves appear to be the most sensitive parts of plants to gaseous air pollutants. Visible foliar injury means that metabolic impairment and cell mortality have occurred and indicates there are probably additional effects occurring, e.g., effects on growth and reproduction.

Foliar injury from ozone is quite common in the eastern United States due to high sustained ambient ozone concentrations. Ozone injury appears as dark spots on the upper surfaces of leaves of deciduous species and as yellow mottling of the needles of evergreen species. Figures 5-1 and 5-2 show examples of ozone injury to evergreen and deciduous species. These types of ozone injury are frequently unique and can sometimes be identified in the field. Other air pollutants cause different types of foliar injury that are often more difficult to distinguish from the effects of natural causes. Some plant species are known to be sensitive to ozone levels slightly above natural background levels.

Sulfur dioxide, fluorides, nitrogen dioxide, ethylene, chlorine, and ammonia can also cause foliar injury.

Ecological Effects

Exposures to air pollutants for long periods of time can cause effects on plant growth, reproduction, and mortality that can change the functioning and structure of the ecosystem. However, ecological effects are more difficult, and take longer to identify than foliar injury. Ecological effects that have been observed within NPS areas are as follows:

- Tree mortality.
- Decreased tree growth.
- Premature leaf drop.
- Reduced numbers of fruit and seed.
- Smaller fruits and cones.
- Impaired pollen germination.
- Delayed bud break.
- Decreased understory canopy coverage.
- Lower shrub productivity.
- Greater susceptibility to diseases and pests.
- Altered plant competition.
- Changes in species richness and diversity.
- Lichen deserts (severe decreases in lichen diversity and abundance).

The National Park Service is conducting studies to determine if air pollution may be the cause of these effects.

Many of these observations of ecological effects have been made either on crop species in agricultural planting or in natural vegetation areas close to stationary pollution sources. In these situations, the ecological effects of air pollution are obvious due to strong spatial gradients in pollution levels near the source of pollution. Identifying such effects in remote natural areas, where the gradient in pollution concentrations over the area is not significant, is more difficult.

Elevated Levels of Potentially Toxic Trace Elements

Potentially toxic trace elements, primarily heavy metals, contained in particulate air pollutants are deposited on the surfaces of living organisms. These elements can in turn be metabolized by plants and consumed by animals.

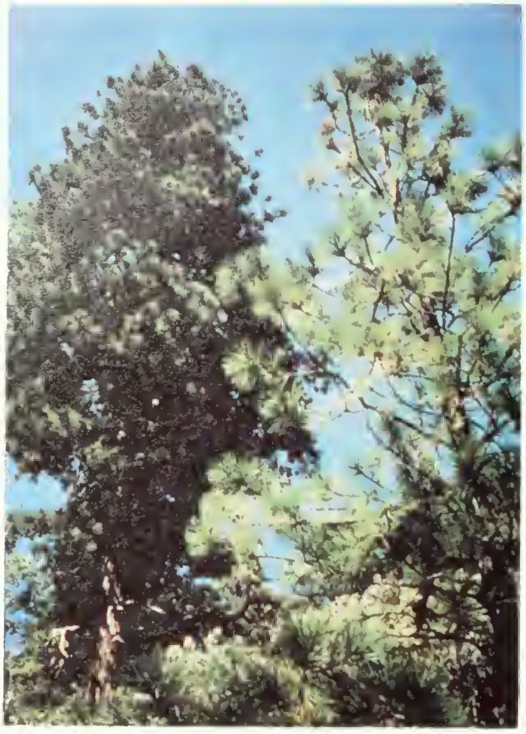


FIGURE 5-1

OZONE INJURY TO PONDEROSA PINE IN SEQUOIA/KINGS CANYON NATIONAL PARKS
The tree on the right shows signs of ozone injury from ambient ozone. The tree on the left has healthy green needles and is tolerant to ozone.

FIGURE 5-2

OZONE INJURED COMMON MILKWEED IN CATOCTIN MOUNTAIN PARK
The dark purple stippling (tiny spotting) on the leaves is caused by ozone.

Manmade pollutants that are most toxic to living organisms and can be transported long distances to remote natural areas include lead, arsenic, mercury, cadmium, chromium, and beryllium. Elements such as iron, vanadium, and sulfur are less toxic but, because high concentrations are normally not found in natural systems, they can indicate the presence of manmade pollution. Elevated levels of trace elements can cause effects, such as foliar injury, stunted growth, or mortality of plants or animals, at various concentrations depending on the sensitivity of the exposed organism. Although direct effects are possible, effects due to cumulative exposure are of greater concern because trace elements once ingested are usually not excreted by the organism. Thus, even when elevated levels of these substances are not necessarily accompanied by detectable damage, continuing study is in order because of potential future effects.

Continuing deposition of pollutants on plant leaf surfaces can lead to high ingested levels of trace elements by herbivores. Since these elements are typically not excreted, they accumulate and undergo "biomagnification," which is the accumulation and concentration of elements through the food chain.

Lichens, mosses, orchids, and bromeliads are sensitive epiphytes used in NPS biological effects program studies. Epiphytes, which are sometimes called air plants, are plants growing on other plants and deriving no sustenance from the support, and obtaining their nutrients directly from the air.

NPS BIOLOGICAL EFFECTS STUDIES

Biological effects studies examine the effects of air pollution on a wide range of plant species in the parks. Figure 5-3 shows the NPS areas where biological effects studies have been or are being conducted. One or more types of effects studies, including biomonitoring studies, have been or are being conducted at a total of 65 parks. The emphasis has been on class I areas and areas where pollution effects are suspected due to proximity of air pollution sources, observed visible injury, or presence of known sensitive species.

Table 5-1 summarizes the types of NPS biological effects studies. These studies involve taking samples of plant material for chemical analysis or surveying for foliar injury or ecological damage in one or more plots selected throughout a park.

The National Park Service uses the biomonitoring studies to detect the first sign of air pollution effects on biological resources in an area. Biomonitoring studies typically use species that are native to the area and known to be sensitive to air pollution. Occasionally, a nonnative biomonitoring species will be used but conditions will be carefully controlled to ensure that the species (or genotype) is not introduced into the area. The sensitive species used in biomonitoring are called biomonitors or bioindicators, and include bioaccumulators. Lichens are an example of bioaccumulators that can be used to detect the presence of elevated levels of airborne elements because such substances tend to accumulate in their tissues. Lichens are also used as bioindicators of sulfur dioxide pollution because they are geographically widespread, and many species are very sensitive to sulfur dioxide and are

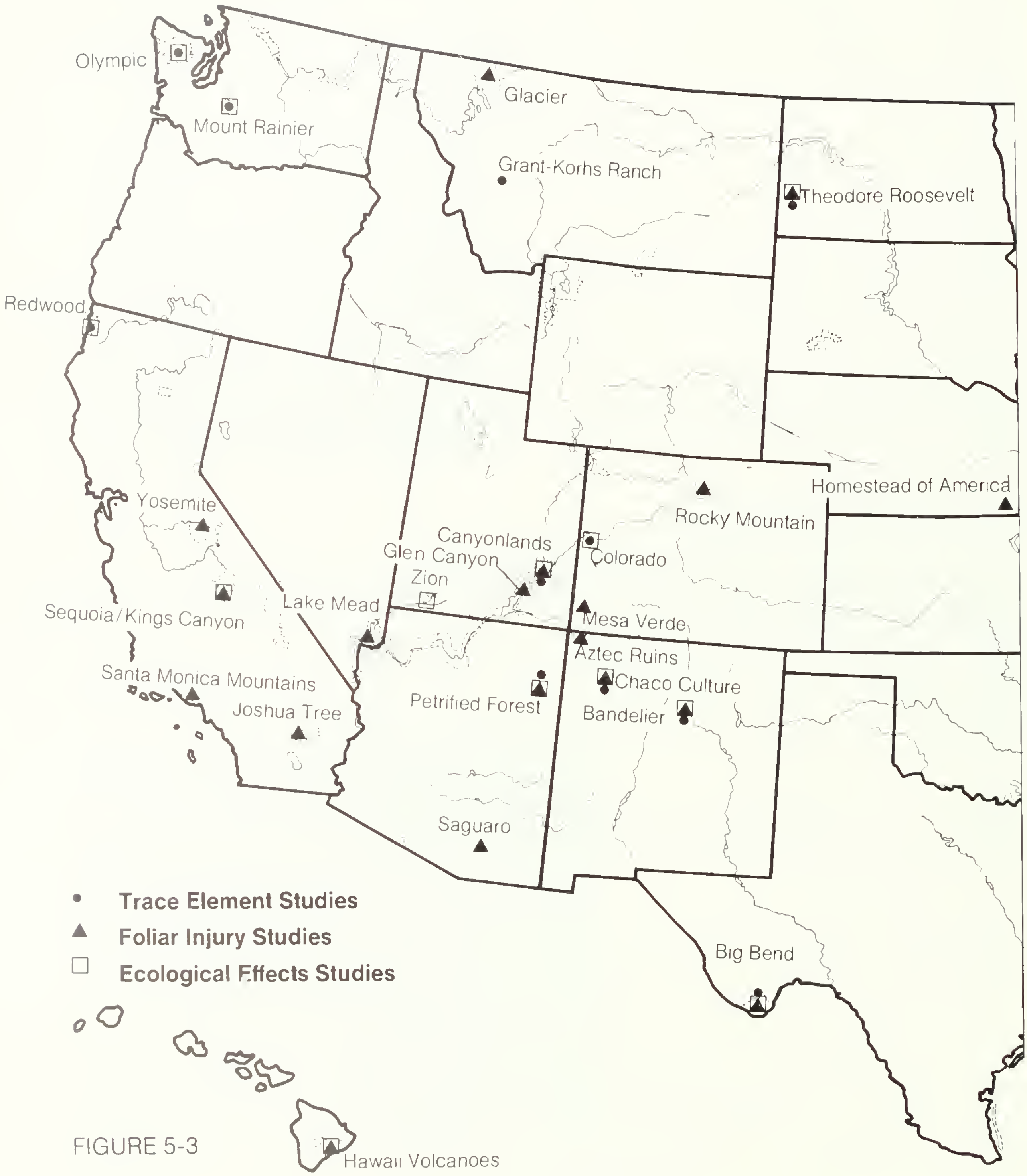


FIGURE 5-3

National Parks Where Studies of the Effects of Air Pollution on Biological Resources Have Been Conducted as of Summer 1985
(Excludes Inventory and Fumigation Work)


Voyageurs
Isle Royale
Acadia
Saint-Gaudens
Cape Cod
Saratoga
Pipestone
Delaware Water Gap
Morristown
Valley Forge
Indiana Dunes
Cuyahoga Valley
Allegheny Portage Railroad
Gettysburg
Catoctin Mountain
Homestead of America
Fort Necessity
Hampton
Rock Creek
Antietam
Chesapeake and Ohio Canal
Friendship Hill
Manassas
LBJ Memorial Grove
Shenandoah
Fredericksburg/Spotsylvania
New River Gorge
Mammoth Cave
Appomattox Court House
Petersburg
Cumberland Gap
Great Smoky Mountains
Buffalo
Natchez Trace Parkway
Big Thicket
Big Cypress
Biscayne
Everglades

Table 5-1. Studies, Methods, and Determinations of NPS Biological Effects Program

Study	Primary Pollutants Of Concern	Primary Target Organism	Methods	Determination
Fumigation	All	Vascular and nonvascular plants	Laboratory or field; measured exposures	Visible injury symptoms; growth yield, and survivorship alterations
Visible Injury Survey	O_3, SO_2, HF NO_x, PAN	Vascular Plants	Systematic, visual assessment on few individuals/many species or many individuals/few species	Extent and severity of visible injury symptoms; foliage retention
Histology	All	Vascular Plants	Compare visible injury at tissue level to macroscopic injury in controlled fumigations and in the field	Definitive pollutant injury signature at tissue level; mechanism of pollutant injury
Elemental Survey	SO_x, HF, NO_x, trace elements, salts, organics	Vascular and nonvascular plants	Lab analyses of elemental concentrations in tissue and soils	Levels of phytotoxic elements; decreased abundance and diversity of species
Biomonitor Garden	All	Small trees, shrubs, herbs & nonvascular plants	Grow pollutant-sensitive species in common garden near pollutant monitor	Visible injury, growth and levels of phytotoxic elemental relative to ambient pollutant concentrations
Permanent Plots	All	Vascular and nonvascular plants	Random selection of sites and plants; detailed assessment of visual injury, growth and elemental content over long periods of time	Trends in visible injury, foliage retention, elemental concentrations and growth
Ecological	All	Vascular and nonvascular plants; insects and animals	Studies on mortality, floristic/genetic diversity, phenology/productivity, growth, litter decomposition, food chains	Monitor survivorship, changes in floristic/genetic diversity, foliage retention, reproduction; annual tree ring growth, mineral cycling, effects on herbivores
Physiological	Gaseous	Vascular Plants	Assessment of carbon budgets	Pollutant effects on net photosynthesis, assimilation rates, etc.

unable to survive when exposed to certain minimum levels. Milkweed is a bioindicator that has been widely used because of its sensitivity to ozone.

The Park Service also conducts inventory and fumigation studies. These studies compile information on biological resources that may be sensitive to air pollutants to help determine whether increased air pollution emissions near an NPS area might endanger biological resources in the park. Inventory studies compile information about the presence and geographical extent of plant species in the parks and have focused on vascular plants and lichens. Fumigation studies involve exposing individual plants (field or laboratory) of a species to carefully controlled amounts of one or more air pollutants at varied frequencies of exposure. These studies help to determine the relationship between air pollution and effects. Species selected for fumigation include sensitive species, the most common species in NPS areas, dominant species, or rare and endangered species.

FINDINGS OF NPS BIOLOGICAL EFFECTS RESEARCH PROGRAM

Figure 5-4 shows the NPS areas where research results have demonstrated that biological resources have been affected by air pollutants. These findings are the result of the studies shown in Figure 5-3. If effects are not shown in Figure 5-4 for parks where studies are shown in Figure 5-3, either no effects were found or the study is not yet complete.

Some kind of effect of air pollution on biological resources has been found at 41 NPS areas to date. The most common effect is foliar injury due to ozone, which has been detected at many units in the eastern United States. Elevated levels of potentially toxic trace elements have been found at 9 NPS units. Ecological effects have also been found at 9 NPS units; the Park Service is conducting studies to determine if air pollution is a cause. Of these 9 units, 3 (Cuyahoga Valley National Recreation Area, Indiana Dunes National Lakeshore, and Santa Monica Mountains National Recreation Area) are located near major urban areas.

The remainder of this section discusses these findings. This research is ongoing with many studies either in progress or planned for the future. Results reported here indicate where biological effects of air pollution have been found as of the summer of 1985. Because it has not been possible to look for all categories of effects at every NPS unit, it is possible that injury may be occurring that has not yet been detected.

Foliar Injury

Table 5-2 shows those parks where foliar injury to common native vascular plants has been documented. Widespread or substantial foliar injury from ozone has been observed in all of these parks. Common trees sensitive to ozone include eastern white pine, tulip poplar, and ponderosa pine.

In the East, foliar injury at Shenandoah National Park was documented on 90 percent of the plants of the most sensitive species (milkweed) and on about 8 percent of the plants of the least sensitive species (black locust) in 1982 and 1984 studies. Almost 70 percent of the eastern white pine trees observed at

FIGURE 5-4

National Parks Where Effects of Air Pollution on Biological Resources Have Been Found as of Summer 1985


Isle Royale
Acadia
Saint-Gaudens
Cape Cod
Saratoga
Pipestone
Delaware Water Gap
Morristown
Indiana Dunes
Cuyahoga Valley
Allegheny Portage Railroad
Gettysburg
Catoctin Mountain
Homestead of America
Fort Necessity
Hampton
Rock Creek
Friendship Hill
Antietam
Chesapeake and Ohio Canal
LBJ Memorial Grove
Manassas
Shenandoah
Fredericksburg/Spotsylvania
New River Gorge
Petersburg
Appomattox Court House
Mammoth Cave
Cumberland Gap
Great Smoky Mountains
Natchez Trace Parkway
Big Thicket
Everglades

TABLE 5-2. NPS UNITS WHERE FOLIAR INJURY TO VASCULAR PLANTS HAS BEEN DOCUMENTED

NPS UNIT	VASCULAR PLANT																																		
	Eastern white pine	Austrian pine	Ponderosa pine	Jack pine	Oak	Black oak	Red oak	Sycamore	Walnut	Black locust	Yellow poplar	White ash	Black cherry	Quaking aspen	Box elder	Willow	Dogwood	Basswood	Redbud	Elderberry	Sassafras	Sunflower	Milkweed	Joe-pie weed	Evening primrose	Witch hazel	Wild grape	Frost grape	Poison ivy	Clematis	Sagebrush (*Artemisia californica*)	Sage (*Salvia leucophylla*)	Laurel sumac	Encelia	Wild buckwheat	Bird's Foot Treefoil
Acadia	X																																			
Cape Cod	X																																			
Fredericksburg/Spotsylvania	X	X									X	X	X				X		X		X		X			X	X									
Gettysburg	X	X									X	X	X				X		X		X		X			X	X									
Great Smoky Mountains	X																						?													
Hampton	X	X									X	X	X				X		X		X		X			X	X									
LBJ Memorial Grove	X																																			
Petersburg	X	X									X	X	X				X		X		X		X			X	X									
Saratoga	X																																			
Shenandoah	X									X	X												X				X			X						
Cuyahoga Valley	X																						X													
Indiana Dunes	X			X			X	X			X	X	X	X	X	X		X		X		X	X	X	X			X	X							
Saguaro			X		X				X																											
Santa Monica Mountains																															X	X	X	X	X	X
Sequoia/Kings Canyon			X			X																														
Yosemite			X																																	

Great Smoky Mountains National Park showed foliar injury, and more than half of the 300 eastern white pine trees studied in 1984 at Acadia National Park showed some foliar injury. In biomonitoring studies at Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park, Gettysburg National Military Park, Hampton National Historic Site, and Petersburg National Battlefield, foliar injury due to ozone has been observed on many species of trees and shrubs. Injury to eastern white pine due to ozone has also been documented at Cape Cod National Seashore, Lyndon Baines Johnson Memorial Grove on the Potomac, and Saratoga National Historical Park.

In the Midwest, foliar injury from ozone is common on white pine, jack pine, and other forest species at Indiana Dunes National Lakeshore. Foliar injury on eastern white pine has also been documented at Cuyahoga Valley National Recreation Area.

In the West, many of the 225 ponderosa pine trees studied in 1984 at Saguaro National Monument showed foliar injury due to ozone. In Sequoia National Park, along the western border of the park adjacent to the polluted San Joaquin Valley, 250 ponderosa and Jeffrey pine trees were evaluated for visible ozone injury. The injury increased from about 50 percent of the trees in 1980-82 to more than 75 percent in 1984. Several species in the coastal sage community at Santa Monica Mountains National Recreation Area show extensive foliar injury due to ozone. Injury to ponderosa and Jeffrey pines due to ozone has also been documented at Yosemite National Park.

Little or no foliar injury due to ozone has been detected by surveys of trees and shrubs in the following 9 NPS units: Big Bend, Canyonlands, Mesa Verde, Rocky Mountain, Theodore Roosevelt, and Voyageurs National Parks; Big Thicket National Preserve; Colorado National Monument; and Glen Canyon National Recreation Area. Foliar effects studies are in progress at 15 areas: Acadia, Biscayne, Everglades, Great Smoky Mountains, Mammoth Cave, Petrified Forest, Sequoia, and Yosemite National Parks; Bandelier, Joshua Tree, and Saguaro National Monuments; Big Cypress National Preserve; Chaco Culture National Historical Park; Cuyahoga Valley National Recreation Area; and Indiana Dunes National Lakeshore.

In the late 1960s, the Park Service found foliar injury at Glacier National Park due to elevated hydrogen fluoride levels. Some injury to herbivores in the park was also observed. The source of the hydrogen fluoride was a nearby aluminum smelter. Controls to reduce emissions were subsequently added to the smelter, and hydrogen fluoride levels have now dropped to natural background levels in vegetation in the park.

A summer of 1984 survey of 25 eastern parks showed widespread foliar injury to milkweed, confirming that ozone is a regional problem. Ozone levels are typically highest during the summer so this is the time when the most injury would be expected. Extensive injury was found at Catoctin Mountain Park, Cuyahoga National Recreation Area, and Shenandoah National Park, with between 67 and 100 percent of the milkweed plants surveyed showing injury on more than 14 percent of the leaf area. Injury on 67 to 100 percent of the milkweed plants surveyed was also found at 8 other parks, although the percentage of leaf area injured was somewhat less. The findings of the milkweed study are summarized in Table 5-3.

Table 5-3. NPS 1984 Milkweed Study Findings

Percentage of Plants with Injury			Percentage of Leaf Area Injured		
0-33%	34-66%	67-100%	0-7%	8-14%	More Than 14%
Rock Creek	Natchez Trace	Fort Necessity	Antietam	Fort Necessity	Shenandoah
Homestead	Saratoga	Shenandoah	Cumberland Gap	Natchez Trace	Cuyahoga Valley
Delaware Water Gap	Gettysburg	Cuyahoga Valley	Saratoga	Petersburg	Catoctin
Pipestone		Antietam	Rock Creek	Gettysburg	
Manassas		Cumberland Gap	Homestead	Chesapeake & Ohio Canal	
Mammoth Cave		Friendship Hill	Friendship Hill		
Valley Forge		Fredericksburg & Spotsylvania	Delaware Water Gap		
Appomattox Court House		Morristown	Fredericksburg & Spotsylvania		
Chesapeake & Ohio Canal		Indiana Dunes	Pipestone		
New River Gorge		Catoctin	Manassas		
Saint Gaudens		Petersburg	Morristown		
			Mammoth Cave		
			Valley Forge		
			Indiana Dunes		
			Appomattox Court House		
			Saint Gaudens		
			New River Gorge		

Ecological Effects

An ecological effect is defined as the alteration of the normal growth, reproduction, or survivorship at the individual, population, or community level. Ecological effects are more complex to identify than foliar injury, since they may result after long exposures to low levels of pollution, and the causal agents may no longer be identifiable. Nevertheless, ecological effects have been observed in several NPS areas across the country. As previously noted, lichens are particularly susceptible to sulfur dioxide. Disappearance or decreases of any lichen species constitute an ecological effect and indicate a potential for ecological effects on vascular plants. Lichens are a primitive type of plant composed of an alga and fungus living cooperatively.

Lichen deserts commonly occur in most urban areas as a result of air pollution. Some species of lichens may die in areas with average annual concentrations of sulfur dioxide as low as 6 ppb (15 micrograms per cubic meter). (See Chapter 4 for a discussion of sulfur dioxide levels at NPS areas.) Because different lichen species have different sensitivities to sulfur dioxide, an inventory study of lichen species in NPS areas can provide an indication of air quality for the area. If many or all of the sensitive species are absent from an area where they would be expected, a high probability exists that air quality is degraded.

Table 5-4 lists the NPS units where ecological effects are being investigated and the type of effects being studied. All of these parks also exhibit foliar injury to vascular plants, except Big Thicket National Preserve where Spanish moss is the affected plant.

Table 5-4. Ecological Effects Being Investigated at NPS Units

Geographical Region	Park	Effect Being Investigated
East	Shenandoah	Decreased growth of eastern white pine Decline of red spruce and other species
South	Big Thicket	Decreased abundance of Spanish moss
	Great Smoky Mountains	Decreased growth of eastern white pine Decline of red spruce
Midwest	Indiana Dunes	Decreased growth of eastern white pine, jack pine, and other species Loss of lichen diversity and abundance
	Cuyahoga Valley	Decreased growth of eastern white pine and other species Loss of lichen diversity and abundance
West	Sequoia/Kings Canyon	Decreased growth of Jeffrey pine

In the East, studies are ongoing at Acadia National Park to relate eastern white pine foliar injury to decreased wood production. Some of the ecological effects here may be due to ozone, although acid deposition may also affect this park. Increased red spruce mortality has been observed in Shenandoah National Park, but the cause of the decline is not clear because both ozone and acid deposition are present. Only one locality in Shenandoah shows significant effects on red spruce.

In the South, elevated metal levels in Spanish moss are one possible cause of the decreased abundance of the species throughout Big Thicket National Preserve. In Great Smoky Mountains National Park, preliminary evidence indicates a narrower distribution of genotypes than expected. Although large numbers of trees show foliar injury due to ozone, the severity of the injury is generally low. Local and regional sources of ozone, heavy metals, and acid rain may be the causes of the ecological effects at this park. Increased red spruce mortality has been observed in Great Smoky Mountains. The effects on red spruce appear to be extensive and are receiving detailed study.

In the Midwest, at Indiana Dunes National Lakeshore, patterns of injury and growth changes in several species have been documented. For example, growth of jack pine juveniles and white pine adults has been reduced due to ozone in certain areas of the park. Also, a decrease in lichen diversity has been documented. Local and regional sources of ozone, sulfur dioxide, and heavy metals are possible causes of these effects. In Cuyahoga Valley National Recreation Area, decreases in eastern white pine growth and severe decreases in lichen diversity and abundance are being documented throughout the unit. Possible causes of these effects are ozone, sulfur dioxide, and heavy metals from regional and local sources.

In the West, at Sequoia/Kings Canyon National Parks, studies are currently underway to determine the relationship between foliar ozone injury and ponderosa pine growth, particularly near the western border of the park where foliar injury is substantial. Studies are also being done at these parks to determine the role of ozone in sequoia seedling establishment. At Santa Monica Mountains National Recreation Area reduced growth has been related to the substantial foliar injury on several species in the coastal sage community. These biological effects could lead to soil destabilization and increased fuel for wildfires. Preliminary surveys indicate that lichen diversity and abundance is generally low. Injury is due to ozone and sulfur dioxide pollution and increases from west to east, as do the pollutant levels.

Biomonitoring plots at Big Bend, Zion, Theodore Roosevelt, and Redwood National Parks have so far shown no ecological effects on lichens due to air pollution. Biomonitoring plots at Colorado National Monument have shown no ecological effects on lichens or vascular plants. The following 15 parks are being investigated for possible ecological effects, but results are not yet available: Acadia, Biscayne, Canyonlands, Everglades, Great Smoky Mountains, Isle Royale, Mammoth Cave, Mount Rainier, Olympic, Petrified Forest, Sequoia/Kings Canyon, and Shenandoah National Parks; Bandelier National Monument; Big Cypress National Preserve; and Chaco Culture National Historical Park.

Elevated Levels of Potentially Toxic Trace Elements

Table 5-5 lists the NPS units where elevated levels of potentially toxic trace elements have been documented, and identifies the elements and organisms in which trace elements have been found.

Table 5-5. NPS Areas Where Elevated Levels of Toxic Trace Elements Have Been Documented

Geographical Region	Park	Findings
East	Shenandoah	Sulfur and lead in lichens
South	Everglades	Sulfur in epiphytes and bromeliads Arsenic and mercury in wildlife
	Great Smoky Mountains	Sulfur in lichens Lead in leaf litter Heavy metals in trees rings
	Big Thicket	Sulfur and heavy metals in Spanish mosses
Midwest	Isle Royale	Sulfur and heavy metals in mosses and lichens
West	Theodore Roosevelt	Zinc in lichens
	Mount Rainier	Arsenic and heavy metals in subalpine fir and lichens
	North Cascades	Arsenic in goat hair
	Olympic	Lead and copper in lichens and mosses
	Grant-Kohrs Ranch	Copper, arsenic, and cadmium in red top grass

In the East, abnormally high concentrations of lead and sulfur have been found in lichens in parts of Shenandoah National Park near urban areas and along roads.

In the South, much evidence for elevated levels of sulfur, lead, and other trace elements has been found in Great Smoky Mountains National Park. Elevated sulfur levels have been measured in epiphytes at several sites near the eastern edge of Everglades National Park. NPS research done at Everglades in 1974 found elevated levels of arsenic and mercury in wildlife. Elevated sulfur and

heavy metals concentrations have been found in Spanish moss at Big Thicket National Preserve.

In the Midwest, elevated levels of sulfur and heavy metals were measured in streams at the north end of Isle Royale National Park in recent NPS research. Elevated concentrations of several heavy metals were also found in mosses and lichens.

In the West, elevated levels of arsenic, lead, cadmium, copper, and zinc were found in subalpine fir foliage and lichens at Mount Rainier National Park. Arsenic levels in fir needles at high elevations were found to be twice what they were at low elevations in the park. A project is underway to determine whether wildlife is being affected by elevated trace elements at Mount Rainier. At Olympic National Park, elevated levels of lead and copper in lichens and mosses have been found, although the levels are lower than at Mount Rainier. At Theodore Roosevelt National Park, some elevated levels of zinc have been documented in lichens.

Ecological effects that may be related to trace elements have also been found in Big Thicket National Preserve and Great Smoky Mountains and Shenandoah National Parks. (These findings were discussed in the previous section on ecological effects.) Studies of the possible ecological effects of elevated trace elements are just beginning at Everglades, Isle Royale, Mount Rainier, and Olympic National Parks. In Theodore Roosevelt, studies have found no current ecological effects from trace elements.

Studies at Big Bend and Redwood National Parks found no elevated levels of heavy metal concentrations. Studies concerning trace elements are currently in progress at Bandelier National Monument; Big Cypress National Preserve; Chaco Culture National Historical Park; and Biscayne, Canyonlands, Everglades, and Petrified Forest National Parks.

Inventory and Fumigation Studies

The National Park Service is developing a computerized inventory of vascular plants throughout the National Park System called NPFLORA. The computerized data base has information on 108 units and data on about 64,000 occurrences of some 14,000 plant species. This data base continues to be expanded.

An inventory of all known lichens, an important bioindicator, in 44 NPS class I areas in the conterminous United States has been compiled. Lichen species lists and known sulfur dioxide sensitivities for each park have been assembled.

Fumigations are being carried out at four federal government and university laboratories and two national parks (Sequoia/Kings Canyon and Great Smoky Mountains) to determine the air pollution sensitivities of selected plant species. Plants being studied include namesake species--those for which parks are named--and species that are widespread throughout the National Park System and suspected of being relatively sensitive. Giant sequoia are an example of namesake species being examined, while chokecherry and aspen are examples of common species under study.

In fumigation studies of six deciduous tree species in the East, individual trees of the same species collected in different parks have been grown together in a common garden and exposed to controlled amounts of ozone. Data from these studies indicate that quaking aspen from Isle Royale and Voyageurs National Parks are more sensitive to injury from ozone than those from Acadia National Park, Cuyahoga Valley National Recreation Area, and Saratoga National Historical Park. Ozone levels are higher at Acadia, Cuyahoga Valley, and Saratoga than at Isle Royale and Voyageurs. Therefore, one hypothesis is that adaptation to elevated ozone levels may have occurred in the more polluted parks. The Park Service is testing this hypothesis. If sensitive genotypes are being eliminated from more polluted NPS units, the species may become more vulnerable to other stresses due to decreased fitness.

POINTS RAISED BY NPS BIOLOGICAL EFFECTS RESEARCH PROGRAM

There are many unanswered questions concerning biological impacts of air pollution in NPS units. Two important questions discussed in this section are currently being studied through the NPS biological effects research program.

1. What Is the Relationship Between Foliar Injury and Ecological Effects?

   In several parks where foliar injury is widespread or substantial, data on plant growth or productivity are being collected in order to quantify the relationship between this effect and ecological damage. At Acadia National Park, eastern white pine is the species of interest. At Sequoia National Park, ponderosa pine is being studied. Coastal sage species have been studied at Santa Monica Mountains National Recreation Area.

   The relationship between foliar injury and plant growth would be expected to differ between species and to vary with factors, including inherited characteristics, season, altitude, soils, geographical location, and nutritional status and age of plant parts. The relationship of foliar injury to ecological effects is a complex one and NPS work can only be expected to elucidate some aspects of it. The analogous questions concerning the relationship of elevated levels of potentially toxic trace elements to ecological effects has similar or greater complexities and uncertainties.

2. What Are the Ecological Implications of Adaptation to Air Pollution?

   In order to survive any environmental stress or change, organisms must adapt; that is, through time, less fit individuals are selected against by environmental stress. The degree to which this is occurring in response to air pollution is unknown and difficult to determine, but some NPS research findings suggest that adaptation may be occurring in some parks. It is also not clear how adaptation of some organisms may affect the structure and function of a park's ecosystem. The adaptation mechanism needs to be understood in order for the National Park Service to judge whether such adaption is a problem from the point of view of the NPS mandate to preserve and protect park resources.

In Great Smoky Mountains National Park, a genetic study has shown that genetic diversity in white pine is less than the overall level of diversity throughout the rest of the natural range of white pine. Air pollution may be playing a role in this reduction of genetic diversity by eliminating sensitive genotypes. In Great Smoky Mountains, preliminary evidence indicates that sensitive strains of eastern white pine may be disappearing. Data from fumigation studies have shown that the ozone sensitivity of quaking aspen in Acadia National Park, Cuyahoga Valley National Recreation Area, and Saratoga National Historical Park (parks with high ozone levels) is lower than the sensitivity in Isle Royale and Voyageurs National Parks (parks with relatively clean air). These data suggest the possibility that adaptation to air pollution may have occurred and that genetic diversity may have been affected. These changes may leave the species more vulnerable to other stresses by reducing the diversity within the species.

6.0 NPS PARTICIPATION IN PROTECTION OF AIR QUALITY RESOURCES

Information from the air quality research program is used to support NPS participation in decisions for protecting and managing air resources. In most cases, the air pollution affecting park resources and values comes from outside the parks. NPS concerns and recommendations regarding proposed or existing air pollution sources are directed to the governmental agency that has permitting or regulatory authority. Cooperation is also elicited from industry to ensure protection of NPS resources. The Clean Air Act requires that the National Park Service be involved in reviewing state implementation plans designed to prevent significant deterioration of air quality and to protect visibility. The Park Service is also required to evaluate the effects that a new air pollution source might have on nearby park resources. The NPS Air Quality Division has servicewide responsibility for ensuring compliance with Clean Air Act requirements, in coordination with NPS regional offices and park units.

This chapter discusses this process and presents some case studies showing how research findings have been used to protect NPS air resources.

REVIEW OF PERMIT APPLICATIONS AND ENVIRONMENTAL ASSESSMENTS

If potential or existing air quality effects on NPS resources occur, and an industrial or energy resource developer wishes to construct a new air pollution source near an NPS unit, the environmental assessment or permit application prepared by the applicant is reviewed. Comments are provided to the governmental agency with the authority to issue air quality permits, which is usually the state in which the proposed project would be located.

More than 250 permit applications were reviewed between 1979 and 1987. Figure 6-1 shows the locations of those proposed projects. The Air Quality Division has had questions or comments on about half of the permits reviewed. Often these comments involve requests for more complete air quality modeling and analysis in order to better substantiate the case made by the applicant that no adverse effects on NPS resources would occur. In some cases, modifications in the proposed emission control technology have been requested to further reduce potential impacts on NPS resources and values. States and applicants often, but not always, comply with the NPS requests.

The state makes the final decision on the approval or denial of the permit application. The permit will be denied if the applicant cannot demonstrate compliance with the applicable air quality standards (increments). If the Park Service certifies that no adverse impact on park resources would occur at the predicted level of emissions, the permit may be approved. However, if the Park Service demonstrates to the satisfaction of the state that an adverse impact would occur even though the standards are expected to be met, the state may then deny the permit. The Clean Air Act requires the federal land manager to make judgments, in some situations, about whether or not a change in air quality will result in an adverse effect on park resources.

When determining whether the changes caused by air pollutants constitute an adverse impact on air quality related values, the Park Service primarily looks at whether the national significance of the area would be diminished, whether the structure and functioning of ecosystems would be impaired, or whether the

FIGURE 6-1

Locations of Proposed Projects Reviewed by the National Park Service Since 1979


Acadia
Shenandoah
Mammoth Cave
Great Smoky Mountains
Congaree Swamp
Everglades
Virgin Islands

quality of the visitor experience would be impaired. The frequency, magnitude, duration, location, and reversibility of the potential impact are also taken into account by answering the following questions:

1. Will the effects last long enough and/or occur frequently enough to impair the structure and functioning of ecosystems in the park, impair visitor experience, or diminish the national significance of the area?

2. Will the effects occur on a scale large enough to impair the structure and functioning of the ecosystems in the park, impair the visitor experience, or diminish the national significance of the area?

3. Are the effects reversible if the stress causing them is removed from the area?

Although the National Park Service carefully evaluates information submitted by permit applicants, and often performs an independent analysis of potential effects on air quality related values, no formal adverse impact determinations have been made that would have prevented the approval of any of the permits issued to date.

The following sections give some examples of the NPS involvement in the review process.

Permit Reviews at Theodore Roosevelt National Park

Between 1977 and 1979, six permit applications were submitted to the state of North Dakota for proposed facilities--three gas-processing plants, one synthetic fuels plant, and two power plants--near Theodore Roosevelt National Park and Lostwood National Wildlife Refuge. Air quality models predicted that the prevention of significant deterioration class I air quality increments for sulfur dioxide would be exceeded by the emissions from five of these sources, and the applicants requested a certification of no adverse impact from the NPS. Responding to these requests required using data available from the visibility monitoring network and the biological effects research program; new analyses were also conducted to determine the potential effects of estimated emissions of fine particulates and sulfur dioxide from the facilities.

In order to assess what effects the facilities might have on visibility at the park, the Air Quality Division, in cooperation with the North Dakota Department of Health, estimated the total amount of fine particulates expected to be added to the air as a result of emissions from the proposed facilities, including the formation of sulfates as a result of sulfur dioxide emissions. Photographs of poor and good visibility conditions at the park were selected from the inventory compiled by the monitoring efforts at the park; two more photographs were then selected to illustrate the change in visibility that would occur as a result of the new emissions. It was then possible to judge the visual effects of the increase in fine particulates when background conditions were poor or good. The National Park Service found the differences between the latter two photographs and the original two were virtually imperceptible, and therefore judged that no adverse effect on visibility would occur.

To assess the potential effects on biological resources, data from the biological effects research program were used and two additional field studies were conducted. Previous research by the Park Service and others indicated that no injury to the plant species present in the park had ever been observed at pollution concentrations predicted to occur as a result of the facilities.

The only potential effects predicted were an increase in sulfur content in lichens and a possible decline in abundance of a few of the most sensitive lichen species. The potential decline was not expected to be of sufficient magnitude to diminish the role of lichens in the park ecosystems. Therefore, the National Park Service concluded that no adverse impact was likely to occur. However, continued study and monitoring of biological resources in the park was recommended to ensure that existing and potential future development in the area would not threaten park ecosystems. As was noted in Chapter 4, monitoring at Theodore Roosevelt National Park indicates that ambient sulfur dioxide levels have fallen from 1982 to 1984. This is associated with efforts by the State, in cooperation with National Park Service, to reduce emissions from all oil and gas production activities in the area.

The NPS decision regarding these permit applications was summarized in the Federal Register, September 20, 1982 (47 FR 41480).

Permit Reviews at Shenandoah National Park

Industrial development near Shenandoah National Park has presented some special problems. Foliar injury due to ozone has been documented on several plant species in Shenandoah, and ambient levels of ozone measured in the park are close to, but not violating, the National Ambient Air Quality Standards. The reason for this high ozone concentration is particularly difficult to determine, because ozone is not directly emitted, but is formed in the atmosphere as the result of the interaction of several different pollutants. Ozone can also be transported long distances.

A number of permit applications have been reviewed for small industrial facilities near Shenandoah which were expected to emit hydrocarbons (key precursors in ozone formation). These sources may, in aggregate, contribute to the formation of ozone in the area, but due to the complexities in the formation of ozone in the atmosphere, it is difficult to determine how much each additional new source might contribute. There are no prevention of significant deterioration increments for ozone; the state is allowed to issue a permit to a new source unless the Park Service can convince the state that an adverse impact on NPS resources would occur. With foliar injury already documented in the park, the Park Service is concerned that adverse impacts may be occurring due to combined emissions from local and distant sources. Recommendations for additional emission controls or emission offsets (requiring a reduction in emissions in one place before allowing increases in another) have been made in several instances in order to minimize the increase in ambient ozone levels.

The Air Quality Division is currently conducting research to identify whether air quality models can be used to determine the sources of ozone pollution at Shenandoah. Preliminary results indicate that as much as 50 percent of the ozone in the Shenandoah area may be the result of emissions in other states.

The National Park Service, the Virginia State Air Pollution Control Board, and the U.S. Environmental Protection Agency are currently working together in formulating possible alternative approaches for addressing the ozone problem at Shenandoah.

Proposed High-Level Nuclear Waste Repository Near Canyonlands National Park

Davis and Lavender Canyons near Canyonlands National Park were being considered by the U.S. Department of Energy, along with several other locations in the United States, for a high-level nuclear waste repository. The Park Service reviewed the environmental assessment prepared by the U.S. Department of Energy and was concerned about the possible impact on park resources and visitors' experiences at Canyonlands if the site were selected.

The Air Quality Division provided technical assistance to the park in analyzing potential impacts on air quality related values. One aspect of the proposed repository of particular concern was that it would be brightly lit for security reasons. This concern prompted an analysis of how the light might affect the view of the night sky from within the park. A model was developed to predict the intensity of the glow and how much of the night sky would be obscured by the glow under different air quality conditions. The results indicated that the light would be noticeable from within the park whether the air were "clean" or "dirty" and the glow would be bright enough to obscure some stars and the Milky Way in some portion of the sky. As would be expected, the night glow was predicted to be greatest at the viewing sites in the park closest to the proposed repository site, but some glow was predicted to be visible from as far away as Grand View Point, about 15 miles from the proposed repository site.

NPS comments on the environmental assessment expressed concern that night lighting at the nuclear repository would detract from visitor enjoyment of the park. Because of this and other potential impacts on park resources and values, the National Park Service asked the U.S. Department of Energy to disqualify the proposed site near Canyonlands. The U.S. Department of Energy subsequently decided not to recommend the Davis or Lavender Canyon sites for more detailed site characterization studies.

DEVELOPMENT OF PROCEDURES FOR PROTECTION OF NPS RESOURCES

While the Park Service has responsibilities for protecting the air resources of the National Park System, other federal or state agencies are charged with developing air quality control plans. Consequently, the Park Service is an active participant in the regulatory development process and works cooperatively with other agencies to promote NPS resource protection objectives.

Incorporation of Park Air Resource Protection Goals in State Implementation Plans

States are required to develop implementation plans detailing how they plan to protect air quality. These plans must include strategies needed to attain National Ambient Air Quality Standards, to prevent significant deterioration of air quality in clean air areas, and to make reasonable progress toward the national visibility goal. Using information and analytical tools developed through the NPS air quality research and monitoring program, the Air Quality Division works with the states to develop their plans to help ensure consistency with federal requirements and park protection goals. For example, states are encouraged to incorporate measures into their plans that provide the National Park Service with sufficient opportunities to be involved in the formal review process for pollution sources that might have an effect on NPS resources. In response to NPS suggestions, some states have established requirements for permit applicants to conduct preconstruction monitoring of air quality related values in affected NPS units.

States are also required to consult with the Park Service before developing visibility protection plans for class I areas. Information from the NPS visibility monitoring network has been used to document existing visibility impairment at all monitored parks. If the Park Service certifies that existing impairment exists in a park area, then a regulatory requirement is triggered. In this case, the states must determine whether the impairment is reasonably attributable to a specific source or small group of sources. The Air Quality Division has developed analytical tools that can be used to identify the major source areas contributing to visibility impairment in a park unit. Information generated through application of these techniques is shared with the states for their consideration in developing visibility protection strategies.

Cooperative Studies

In addition to the required regulatory programs that states must administer, some states have been voluntarily working together to analyze and develop regional approaches to pollution control. The National Park Service participated in a cooperative multi-state (Colorado, Wyoming, Montana, Utah, Idaho, and New Mexico) effort, in conjunction with the U.S. Forest Service and Bureau of Land Management, to evaluate options for the ultimate development of state visibility standards. This two-year study, called the Rocky Mountain Visibility Project, was completed in early 1985. A document was prepared that describes the parameters that could be used to define a visibility standard and discusses the technical and policy issues related to such a standard.

These same states plus six additional western states (Arizona, Washington, Oregon, California, North Dakota, and Nevada) conducted a two-year acid deposition study that began in September 1985 called State Acid Rain Project (STAR). As part of this study, emissions inventories for acid deposition and visibility-reducing precursor pollutants were compiled and refined, atmospheric aerosols were characterized, existing and potential options for regional cooperation were analyzed, and model permitting procedures to address acid deposition effects of new air pollution sources on air quality-related values are being developed. The Air Quality Division has provided technical assistance to STAR participants to ensure that NPS concerns are addressed.

Interagency Visibility Task Force

The Park Service has participated in interagency task forces convened by the U.S. Environmental Protection Agency to help develop federal regulations to protect visibility. The National Park Service had a major role in establishing a visibility impact analysis requirement for all new sources that might affect visibility in a class I area. In addition the Park Service successfully encouraged the U.S. Environmental Protection Agency to establish a national visibility monitoring network, using state-of-the-art equipment to document existing conditions and assess long-term trends. Air Quality Division staff have also been involved in an interagency study of long-term strategies for controlling regional haze. The report issued by this task force examined regulatory and research issues related to developing haze control approaches and included findings and recommendations.

EFFECTS ON AIR QUALITY FROM ACTIVITIES WITHIN NPS UNITS

When the sources of air pollutants are within the parks themselves, the Park Service must make resource management decisions balancing the need for the activities emitting pollutants and the need to protect park resources from the pollutants. In any event, all air pollution sources within parks, including prescribed fires, must comply with all federal, state, and local laws and regulations.

Smoke Management Plan for Grand Canyon National Park

The Park Service uses controlled burning to manage the forests in NPS areas and to thin forest stands and reduce the risk of wildfires. Burning, however, produces smoke that can affect visibility and visitor enjoyment in the parks. An incident in September 1980 served to increase public awareness of this problem when smoke from a burn on the North Rim of the Grand Canyon was transported into the canyon. The smoke significantly reduced visibility, impairing the visitors' view of the canyon. The Air Quality Division is conducting a smoke management research program in an attempt to develop a procedure to be used by park personnel to help select optimal times for conducting burns in order to minimize undesirable effects on visibility.

This research includes developing the capability of forecasting weather conditions in order to begin burns when optimal conditions are expected for adequate smoke dispersal. An objective forecasting technique is being developed that will be used by park personnel to predict the likelihood of optimal conditions over a 24- or 48-hour period. If this program is successful at Grand Canyon, it may be possible to apply the same approach at several other parks with similar problems.

Yellowstone Boilers

The boilers used by the concessionaires at Yellowstone National Park to produce heat for the lodging facilities were old and emitting enough sulfur dioxide to cause noticeable problems in the park. In addition to concerns about potential effects on park resources and visitors, there were suspicions that the

pollution was actually damaging the paint on employees' cars. Everyone agreed that the situation should be corrected and the NPS Denver Service Center was retained to design new boilers for the park. Through the use of air quality models, the Air Quality Division helped develop a design and select a fuel that would minimize future pollution emissions.

INCORPORATION OF AIR QUALITY CONCERNS INTO PLANNING AND INTERPRETIVE ACTIVITIES

Air pollution has been recognized as one of the most serious threats to the resources and values of the National Park System. Since the Park Service holds these resources in trust for present and future generations, it is important for the public to understand how air pollution affects park resources. Interpretive activities and park management plans provide excellent vehicles for conveying and documenting air quality concerns.

Encouragement of Public Awareness of Air Quality

Air quality information is disseminated to NPS units for use in interpretive activities and exhibits. Visibility and biological effects data obtained through the NPS air quality research program have been summarized in slide presentations, pamphlets, reports, posters, and wayside exhibits. In 1983, only a half dozen parks were using air quality information in interpretive activities. By 1987, over 70 park units had received a set of slides compiled by the Air Quality Division, depicting air pollution sources and effects on park resources; also, 20 parks had developed air quality exhibits. The information is used by park personnel to promote public awareness of the air resource in the parks. Air quality interpretive activities have also informed park visitors about the air resource issues facing the National Park Service.

Participation in Resource Management Planning

The Air Quality Division works with individual parks, regional offices, and the Denver Service Center to ensure that air quality is adequately addressed in NPS planning documents, such as the statements for management, resource management plans, general management plans, and specific project plans. One of the goals is to encourage the treatment of air quality as a resource that should be protected and managed. Park plans provide good vehicles for documenting current air quality conditions and any air quality monitoring or research being done in the park. The Air Quality Division provides technical information for use in planning documents and reviews project statements to ensure that their goals are consistent with the needs that have been identified by research that has been conducted to date.

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